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AIR BORNE EMISSIONS FROM MUNICIPAL INCINERATORS

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Air Borne Emissions from Municipal Incinerators

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16. Abstracts The state of knowledge on emissions from municipal incinerators is reviewed with recommendations for needed work. The results of an experimental study of gaseous emissions, refuse, quench water, and residual ash from four municipal incinerators in the New York City metropolitan area are described. The tabulated data indicate that municipal incinerator gaseous effluent is significantly richer in inorganics such as hydrogen chloride, sulfuric acid, and sulfur dioxide than in organics such as hydrocarbons, aldehydes, alcohols, ketones, esters, and organic acids. Control of these emissions is needed to eliminate corrosion. Limitations control of these emissions in the general literature suggest the need for supplementary and new studies. Specific research areas are recommended. An annotated bibliography of books, reports, periodical references and other miscellaneous publications is appended.

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Forward

One of the significant by-products of the intricate chemical reactions which sustain life in all forms is waste. Those mechanisms, both natural and synthetically evolved, which have propagated and multiplied the homo sapien form are indeed prime examples. Human population has not only rapidly increased, but has concentrated in chosen geographical locations. Amassed in a synthetic environment designed for modern existence, man continues to live, multiply and produce enormous quantities of waste.

Just as a bacterial growth can be poisoned in its own excretion, so man can be destroyed in its own waste unless means are taken to remove the waste at a rate at least equal to the rate of its production.

In large cities, the solid waste is being constantly removed from the environment and destroyed in a number of ways. One of the most efficient is by burning (incinerating) it. Thus large units have been designed and constructed for the purpose of economical disposal.

But alas, matter and/or energy can neither be created nor destroyed, only merely changed in form. Thus solid waste is presently converted (via incineration) in part to gases and liquids. The gases are dispersed into the life-essential air and the liquids into our rivers, bays and oceans. Clearly, this system is not completely satisfactory. True, the solid volume of the waste is reduced significantly, but little is being done in this country to reduce obnoxious gas and liquid emissions from incinerators.

The products of the combustion of solid waste are many and varied. They include numerous classes of organic as well as inorganic compounds, certainly not all identified. The composition of the effluent, in addition,

changes radically with the nature of the refuse charge, which is in itself constantly changing, and the incinerator operational conditions.

The relationship among these changing parameters has not been satisfactorily established. The rate of discharge of many of the known emissions has not been adequately recorded. The synergestic, accumulative effects of these emissions on life remains a mystery. An understanding of their nature, quantity, and effects and subsequently of their control is prerequisite to the total elimination of substances which can upset and eventually destroy the ecological cycles which are so necessary to life.

Elimination of waste is today as necessary to the efficient function of a life colony as is its food, water and air supply. The study of ways and means of disposal is therefore quite important and indeed essential. Since incineration is by far the most widely used method for the disposal of solid waste in large metropolitan areas, the overall efficiency of incinerator units used for this purpose must be evaluated in efforts to optimize their operation.

Air Borne Emissions
from Municipal Incinerators

July 1969

Summary

Studies of emissions from municipal incinerators have been quite limited in number as well as in scope. This report presents a review on the general state of knowledge with recommendations for further, needed work and the results of an experimental study of gaseous emissions, refuse, quench water and residual ash from four municipal incinerators in the New York City metropolitan area. An annotated bibliography of books, reports, periodical references and other miscellaneous publications dealing with the subject matter is included as an appendix.

The review which follows summarizes findings resulting from a search of the literature, dealing with studies of emissions from municipal incinerators, conducted as part of a phase I effort in the spring and summer of 1967 prior to the experimental investigation. All articles were reviewed and evaluated with the purpose of presenting a summary report on the general state of knowledge.

The results of outstanding investigations are presented discussed and evaluated in publications by Rehm, F.R. (1), Kanter, C.V. et al. (2), Tuttle, W.N. and Feldatein, M. (3), Stenburg, R.L. et al. (4) and (5), Kaiser, E.R. (6), Hangebrauck, R.P. et al. (7), Flood, L.P. (8), Jens, W. and Rehm, F.R. (9) and Walker, A.B. (10). Some of these studies were concerned only with particulate, CO_2, CO, H_2O, O_2 and N_2 emissions under normal incinerator operating conditions. Some were in addition concerned with how the respective quantity of each emission was affected by e.g. underfire and overfire air variations, agitation of fire bed,

amount of refuse loaded, batch vs. continuous incineration, size and type of incinerator and cleaning equipment. A limited number of the papers reviewed, which were concerned with emissions from municipal incinerators, included data on emissions other than particulates, CO_2, CO, H_2O, O_2 and N_2. Outstanding among this group are publications by Hutchinson, D.H. (11), Stanford Research Institute (12), Kanter, C.V. et al. (2), Stenburg, R.L. et al. (5) and Walker, A.B. (10). Included in such publications were data from the quantitation of oxides of sulfur, sometimes ammonia and organic pollutants. The organic pollutants were usually classes of compounds having the same functional group. Each class or family was then quantitated and reported as the equivalent of a representative member of that class, Thus a typical analysis included values for CO_2, CO, O_2, N_2, water perhaps acetylene and ammonia, particulate matter, oxides of nitrogen as NO_2, oxides of sulfur as SO_2, total tydrocarbons as hexane (or methane), aldehydes as CH_2O, and organic acids as acetic acid. These analyses have in general been conducted during normal, steady-state incinerator operating conditions.

More detailed identification and quantitation of emissions have been restricted to particulates and hydrocarbons. Papers by Kanter, C.V., et al. (2), Kaiser, E.R. (6), Jens, W. and Rehm, F.R. (9) and others contain also the results of detailed analyses of particulates from stack effluent and collector catch. The data of Jens and Rehm included values for 19 metals, 5 anions and 2 non-metals present in this emission. The data of Kanter et al. included values for 21 metals present. The results of a relatively detailed source-sampling program to determine the pollutant

emissions from many types of combustion processes have been reported by Hangebrauck, R.P. et al. (7). Emission levels of polynuclear hydrocarbons, particulate matter, CO, total gaseous hydrocarbons, oxides of nitrogen, oxides of sulfur and formaldehyde were measured for (1) heat-generation sources that burned coal, fuel oil and natural gas, and (2) incinerators that burned municipal-type refuse. Also, the polynuclear hydrocarbon concentrations in particulate matter emitted from open fires burning household refuse, automobile tires, grass and hedge clippings, and automobile bodies were determined. Emission levels of benzo(a) pyrene and a number of other specific polynuclear hydrocarbons were given particular consideration because of the demonstrated or potential carcinogenic activity of these compounds. Using gas-chromatographic techniques, Tuttle, W.N. and Feldstein,M. (3) have analyzed the effluents from a series of incinerators (not all municipal) for C_2 to C_6 hydrocarbons. Their resulting publication contains data from the quantitation of C_3, C_4, C_5 and C_6 fractions (saturated plus unsaturated) and from the identification and quantitation of a number of specific hydrocarbons e.g., acetylene, ethylene, ethane, n- and i-butane, 3-methylbutene-1, pentene-1, n-pentane, 2-methylbutene-2, 2-methylpentane, 3-methylpentane and n-hexane.

The paper by Kaiser, E.R. (6) appears to be the only publication resulting from a study of the effluents from municipal incinerators in the New York City metropolitan area. Recorded gaseous emission data do not however include values for oxides of nitrogen, oxides of sulfur, NH_3 or any organics, although as noted above, particulate composition was well defined.

Chemical analyses of stack effluents at start-up have in general been limited mostly to CO_2, CO, H_2O, N_2, O_2 and particulates. Seasonal variations in the composition of air borne emissions from municipal incinerators have not as yet been recorded. Variations in the rate of discharge when the incinerator is being operated at design capacity and/or at capacity loading that meets local air pollution control requirements have not been determined for many of the effluent constituents. In addition, little or no emphasis has been plac.d on the detection of those emission components which are toxic or potentially toxic to man e.g. HCN, HF, HCl, H_2S, Cl_2, organometallics and volatile fluorides and phosphorous compounds.

Clearly then, a great deal of additional data must be recorded before the effect of stack effluents from municipal incinerators (especially from those in the New York City metropolitan area) on air pollution can be fully evaluated.

It would appear that the air borne emission from the domestic or flue-fed incinerator was chosen as the subject for a more detailed analytical study. Thus the Bureau of Laboratory of the Department of Air Pollution Control of the City of New York developed a comprehensive procedure for the sampling and chemical analysis of the effluents of apartment house incinerators. The results of the experimental development work and of actual field studies appeared in a publication by Jacobs, M.B. et al. in 1958 (13). The gases and vapors quantitated during the course of this program were: SO_2, aldehydes as CH_2O, organic acids as CH_3COOH, NH_3, H_2S, benzene, esters as ethyl acetate, CO, CO_2, O_2, oxidizable sulfur compounds, oxides of nitrogen

as NO_2, phenols and hydrocarbons as methane. The published results of a parallel study conducted by Kaiser, E.R. and co-workers in 1959 (14) included, in addition, data from a qualitative mass-spectrographic analysis which indicated that methane, ethylene, acetaldehyde, methyl and ethyl alcohol, propylene and acetone were also present in emissions from flue-fed incinerators. Other emission data from domestic incinerators studies appeared in publications by Hutchison, D.H. (11), Stanford Research Institute (12), Kanter, C.F. et al. (2), Sterling, M. and Bower, R. (15), Tuttle, W.N. and Feldstein, M. (3) (also from municipal incinerators) and Walker, A.B. (10).

The most detailed analytical study, one of the effluents from back yard incinerators, was conducted by Yocom, J.E. and coworkers in 1956 (16). Gaseous and normally liquid materials from the effluent were collected in a conventional freeze-out train and analyzed by infrared and ultraviolet spectrophotometry and wet chemistry. Recorded data included values for methanol, ethylene, acetone, methane, acetylene, alpha olefins, carbonyl sulfide, benzene, acids as acetic acid, phenols as phenol, aldehydes as CH_2O, ammonia, oxides of nitrogen as NO_2, acetaldehyde, esters and guaiacol as well as for CO and CO_2. Some fractions could not be identified. This work emphasized the extreme complexity of incinerator gases. It also pointed out the need for more work toward identifying the chemical nature of this form of pollution as a means of assessing its importance.

The effects of high volatile fuel on incinerator effluents were investigated by Stenburg, R.L. et al. in 1961 (17). All studies were made in an experimental, multiple chamber, prototype incinerator. Asphalt saturated felt roofing was the high volatile fuel component selected for these tests. Recorded emission data included values for CO, CO_2, total hydrocarbons, NO_2, formaldehyde and particulates. The effect of underfire airflow, excess air, secondary air, temperature and small vs. large batch charges on some of these emissions was also investigated. Rose, Jr., A.H. and co-workers (18) also employed a small, experimental, multiple chamber, prototype incinerator to study the air pollution effects of incinerator firing practices and combustion air distribution. Specifically, these investigators obtained information about the effect of varying (1) amount and distribution of combustion air, (2) burning rate, (3) amount of fuel per charge, and (4) the interval between stoking the burning fuel bed on the particulate, hydrocarbon, CO, oxides of nitrogen and odor emission.

An annotated bibliography of books, reports, periodical references and other miscellaneous publications dealing with emissions from incineration of refuse is included as an Appendix.

Seasonal variations in the general composition of the refuse, the general composition of the stack gaseous emission and quench water and the organic content of residual ash were experimentally evaluated using the East 73rd St. municipal incinerator plant in Manhattan, N.Y.C, Seasonal emissions in lbs./ton of refuse were generally highest in the spring and lowest in the summer. The lowest quantity of hydrogen chloride was found

in samples collected in the fall (2.7 lbs./ton of refuse); the highest quantities were found in the winter (6.4 lbs./ton of refuse) and in the spring (8.6 lbs./ton of refuse). The refuse was richer in polymeric (plastic) materials during these two seasons. SO_2 and H_2SO_4 values were related. They ranged from 1.5 to 8 lbs./ton of refuse for SO_2 and 5.3 to 17.5 lbs./ton of refuse for H_2SO_4. Total organic acid values (0.11, 0.14, 0.16, 0.41 lbs./ton of refuse) remained essentially constant as did those for total aldehydes (0.10 to 0.3 lbs./ton of refuse).

The dissolved solids content of the quench water was lowest in the spring and highest in the winter. The ether-soluble organic content of the residual ash was lowest in the winter and highest in the spring. Summer and fall quench water and residual ash did not seem to differ significantly.

The general composition of the refuse, of the stack gaseous emission and of the quench water, and also the organic content of residual ash from four different types of municipal incinerators in the New York City metropolitan area were experimentally evaluated. The lowest rate of discharge values (1.3, 1.8 lbs. SO_2/ton of refuse; 2.3, 3.9 lbs. H_2SO_4/ton of refuse; 1.4, 1.4 lbs. HCl/ton of refuse; 0.06, 0.06 lbs. organic acids/ton of refuse) were recorded at the Flushing incinerator plant, a batch-type unit. Residual ash at this plant however, was rich in gross, unburned, organic matter clearly indicating incomplete incineration (relatively inefficient combustion). Thus in evaluating and comparing the relative incineration efficiencies of various incinerator plants, it is important to consider not only the

quantities of air borne emission per ton of refuse incinerated but also the nature of the furnace residue for obviously, low emission values can result from incomplete burning of the solid waste charge.

From three continuous units, the lowest rates of discharge were recorded at the Hamilton Avenue incinerator plant (1.5, 2.1 lbs. SO_2/ton of refuse; 0.04, 0.001 lbs. NO_2/ton of refuse; 0.09, 0.2 lbs. total hydrocarbons/ton of refuse; 2.2, 5.0 lbs. HCl/ton of refuse; 5.3, 7.5 lbs. H_2SO_4/ton of refuse). This plant is the only one of the three studied without water sprays. It is also the only one which burns a noticeable quantity of industrial refuse. Residual ash samples from this site however, contained the largest amount of ether-soluble organic material.

Air borne emissions from the East 73rd Street incinerator were relatively richer in SO_2 and H_2SO_4. The Oceanside incinerator gaseous stack effluent had the highest hydrocarbon content (3.9, 6.3 lbs./ton of refuse). Hydrogen fluoride was found in the effluent from three of four units only in the winter samples (0.002 to 0.03 lbs./ton of refuse).

In general, the components of the gaseous effluent resulting from the incineration of municipal refuse are many and representative of numerous classes of both organic and inorganic substances. Aliphatic and aromatic hydrocarbons, organic acids, alcohols, keto alcohols, ketones, aldehydes, phenols, halogen and other inorganic acids and inorganic acid anhydrides were found. The air borne emission however, is significantly richer in inorganics such as hydrogen chloride, sulfuric acid and sulfur oxides than in organics. This is indicative of high combustion efficiency. Also

included in the emission are the very toxic hydrogen cyanide and selenium. Essentially all of the selenium and/or its compounds was concentrated in the fly-ash.

The concentration of total hydrocarbons as methane in municipal incinerators stack effluent varied significantly over a relatively short period of days. Peak values of 350 and 410 ppm/v were recorded. Such variations in the hydrocarbons emission concentration and possibly in the concentration of other species must be seriously considered in evaluating average rate of discharge data based on limited measurements.

Preface

A study of air borne emissions from municipal incinerators in the New York City Metropolitan area was initiated at New York University, Chemical Engineering Department, in December, 1966 under contract No. PH 86-67-62, with the Department of Health, Education and Welfare, Public Health Service, Mr. Clarence A. Clemons, Project Officer. Work was continued for a second year under contract PH 86-68-121. This report summarizes the findings of an initial literature search, includes an annotated bibliography, describes in detail the experimental work which was conducted and presents, interprets, evaluates and comments on all of the recorded experimental data. A number of significant facts regarding the incineration of municipal refuse came to light as a result of this study. The statements, findings, conclusions, recommendations, and other data in this report do not necessarily reflect the views of the Department of Health, Education and Welfare.

The main participants in this study program were: Arrigo A. Carotti (project director - Research Scientist), Russel A. Smith (Senior Chemist - Associate Research Scientist), Mrs. Gonul Kocamustafaogullari (Analytical Chemist - Assistant Research Scientist), John Hornyak (Laboratory Technician), and Salah Rahal (Research Assistant). This report was written by A. A. Carotti.

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We are pleased to acknowledge the expert advice received throughout from Mr. Elmer R. Kaiser, of the Chemical Engineering Department of New York University, who participated in this program as consultant. We are also indebted to Mr. M.M. Feldman, P.E., Acting Commissioner and Mr. A. Cuciti, P.E., Principal Engineer of the Sanitation Department of New York City for permission to conduct our studies at the various municipal incinerator plants and for making available to us valuable information regarding the operation of the units. Their spontaneous and courteous cooperation as well as the cooperation of a number of the various plants' personnel was gratefully appreciated. We should in addition like to express our thanks and appreciation to Professor Lee Wikstrom of the Chemical Engineering Department of New York University, who assisted in the literature search conducted during the first six months and to Mr. Charles Lance (Research Aide) who assisted with the sampling during the last five months of the contractual work.

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Introduction

The contribution of domestic, commercial and municipal incinerators to the overall air pollution problem of our urban communities is known to be significant. The incineration of a complex fuel such as municipal refuse can be expected to give rise to a great number of both inorganic and organic solid, liquid and gaseous products many of which are discharged from a stack.

Emphasis however, has been placed only on the measurement of selected stack emissions such as particulates, oxides of carbon, sulfur and nitrogen and a few groups of organics. A comprehensive quantitative evaluation of the products from the incineration of municipal refuse has not as yet been carried out.

Thus, a study of gaseous, air borne emissions, quench water and ash from municipal incinerators in the New York City metropolitan area was initiated at New York University in December, 1966 under contract (No. PH 86-67-62) with the Department of Health, Education and Welfare, Public Health Service. Work was continued for a second year under contract PH 86-68-121. The first phase of the program involved a literature survey and data review on air borne emissions from municipal incinerators with subsequent preparation of an annotated bibliography of the literature surveyed and a special report to summarize the current state of knowledge of incinerator emissions including recommendations for further studies. The second phase involved an experimental study and included specifically the following:

1.) An evaluation of seasonal variations in the general composition of the refuse, the general composition of the stack emission and of the quench water, and in the organic content of the furnace ash from one municipal incinerator, 2.) a comparison of the charge, the composition of the stack emission and quench water and of the organic content of the furnace ash from each of four different types of municipal incinerators, and 3.) a detailed quantitation of the gaseous effluent from one incinerator.

The East 73rd Street Municipal Incinerator in Manhattan, NYC was chosen for the seasonal variation study 1) above and the Oceanside Municipal Incinerator in Hempstead, L.I. as the sampling site for the detailed analytical study 3) above. The above and two other municipal incinerators, namely the Hamilton Ave. in Brooklyn, N.Y.C. and the Flushing in Queens, N.Y.C. were sampled both in the Fall, 1968 and in the Winter of 1968-69 as part of the comparison study 2) above.

Municipal Incinerators

The East 73rd Street Municipal Incinerator(*): The East 73rd Street Incinerator is one of eleven municipal plants serving the City of New York. It was placed inoperation in early 1957. This 660 ton per day plant has maintained an annual performance record of over 94% of design capacity.

The following outlines pertinent, operational parameters: Furnaces - Three, each nominally rated at 220 tons/24 hours. Plant capacity, 660 T/D (continuous feed with two tandem bar and key stokers).

Gas cooled by air and water spray from 1800°F to 650°F.

Ratio - Air 40,000 CFM @ 90°F; water at 150 g.p.m. (roughly estimated that about 1/3 of water is not vaporized).

Stokers - Two tandem traveling bar and key grates. Feeding and drying grate inclined at 25°. Combustion grate is horizontal.

Forced Draft Fans - One per furnace; manual control vanes. Capacity of 29,000 CFM @ 6.5" w.g.

Overfire Air Fans - One per furnace; capacity of 3,000 CFM @ 30" w.g. (introduced through 14 nozzles).

Wall Cooling Fans - One per furnace; capacity at 3000 CFM @ 3.75" w.g. (introduced through holes in silicon carbide blocks lining lower side walls of furnace).

Induced Draft Fans - One per furnace; capacity of 190,000 CFM @ 5.3" w.g. and 700°F.

Refuse feeds continuously through water-cooled chutes by gravity onto traveling grate stokers in rectangular, refractory lined furnaces. Lower portion of walls are built-up with air-cooled silicon carbide shapes.

The residue, which drops through a bifurcated chute to either of two ash conveyors, is water quenched and conveyed by drag chain flight conveyors into residue trucks. The continuous feeding permits high

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(*) City of New York, Department of Sanitation; Bureau of Waste Disposal, E. 73rd Street Incinerator, E. 73rd Street and F.D.R. Drive, Manhattan; M.M. Feldman, P.E. Acting Commissioner - A. Cuciti, P.E., Principal Engineer (1967)

burning rates at temperatures of 1800°F ± 200°F under steady state conditions. Each furnace has a cooling chamber with air ports, water sprays, and baffles through which the hot gases must pass. The gas temperature is reduced to approximately 650°F by a combination of air injection and water spray. The cooled gases enter the multicone cyclone separators which remove the fly ash and pass through the induced draft fan and out of the stack. Each of the three stacks (one from each furnace) leads to a common flue and chimney. Samples were taken at a point, removed from bends, fans, etc., in the horizontal common flue on the roof.

Fly ash from cyclone collectors is conveyed by drag chain conveyors to the residue conveyor for disposal with the residue. Fly ash deposited in cooling chamber is sluiced into the residue conveyor troughs.

The East 73rd Street municipal incinerator was chosen for the seasonal variation study. Only two furnaces were in operation when samples were taken during the Spring, 1968 and Winter 1968-69. All three furnaces were in use for a good part of the Summer. However, when the Summer samples were taken, the incinerator was said to burn "somewhat slow". A value of 200 tons per day for each unit or a plant total of 600 tons per day was safely assumed. During the Fall season, samples were taken when both two and three furnaces were in operation. Thus with the exception of the "somewhat slow" Summer period, all other samples and measurements were taken while the incinerator plant was operating normally and under steady state conditions. Temperatures

recorded during sampling are tabulated with respective analytical and rate of discharge data.

The Hamilton Ave. Municipal Incinerator: The modern Hamilton Ave. Municipal plant in Brooklyn, N.Y.C. is a continuous feed unit with four furnaces each nominally rated at 250 tons per day. Refuse feeds continuously through water-cooled chutes by gravity onto traveling grate stokers in rectangular, refractory-lined furnaces. The continuous feeding permits burning rates at temperatures of 1800°F under steady state conditions. Each furnace has a cooling chamber with air ports but no water sprays. The hot gases, from each furnace, enter a baffled settling chamber for removal of fly ash and pass through an induced draft fan before being emitted from the stack. There are two chimneys with two flues leading to each. With the exception of the water sprays, the number (but not the design) and capacity of furnaces and the stack and chimney layout, the Hamilton Ave. and the East 73rd St. incinerators are essentially identical. Samples and measurements were taken at a point of one chimney about 50 feet from the base. In every case, the incinerator plant was operating normally and under steady state conditions. Temperatures recorded during sampling are tabulated with respective analytical and rate of discharge data.

The Oceanside Municipal Incinerator: The modern Oceanside Municipal Incinerator plant in Hempstead, L.I. is a continuous feed unit with two 10' x 44' x 52', four section furnaces each nominally rated at 300 to 310 tons per day and a smaller three section furnace, with arch and water sprays which cool the hot furnace gases before they issue from the

stack via an induced draft fan, nominally rated at 150 tons per day. Each of the large furnaces embodies four 11' reciprocating or rocking grates. Heat generated from the combustion of the refuse converts water in boiler tubes to steam which runs turbines for inhouse electric power generation. Sea water from the nearby Reynolds Channel is used to quench and wash the solid combustion residue. The effluent from each of the two large furnaces passes through 24 fly-ash arrestors (cyclones) before issuing from the stacks. The emission from the No. 3 furnace does not pass through fly-ash arrestors. Overfire air is fed at a rate of from 7,000 to 11,000 $ft.^3$/min. and underfire air at a rate of about 22,000 $ft.^3$/min. The furnace temperature with normally dry refuse ranges from 1700 to 1750°F.

Samples for exhaustive analysis were taken from one of the large, (No. 2) furnaces after the fly-ash arrestors, downstream of the induced draft fan. The temperature at this point was always about 600°F. The samples for the comparison study were taken from the No. 3 unit, both in the Fall and in the Winter, about 10 feet downstream of the induced draft fan. Corresponding velocity measurements were made at a point above the base of the chimney about 5 feet above roof-top. Temperatures recorded during measurements are tabulated with respective analytical and rate of discharge data.

All samples and measurements were taken while the incinerator plant was operating normally and under steady state condition.

The Flushing Municipal Incinerator: This municipal plant, located in Queens, New York City is a batch type unit with three furnaces each rated at 100 tons per day. Each furnace embodies a rocking grate which moves the residue forward towards the front to a dump grate. Occasional manual stoking is necessary. The combustion air is supplied via natural draft. Furnace temperatures average between 1400-1500°F at peak burning. 1200°F temperatures are recorded at loading (approx. every 20 minutes). The hot gases exit at the rear of the furnace into a cross flue the length of the plant. They then pass into a common stack and chimney. There is some fly-ash settling along flue and stack where there are volocity drops. Samples and velocity measurements were taken at a point in the common stack about 15 feet from the base of the chimney. Samples were taken with both two and three furnaces in operation during the Fall and when all three furnaces were in operation during the Winter, but in all cases, the incinerator plant was operating normally and under steady state conditions. Temperatures recorded during sampling are tabulated with respective analytical and rate of discharge data.

The Refuse

The composition of municipal refuse at the Oceanside Municipal Incinerator plant was studied by Kaiser, E.R., Zeit, C.D. and McCaffery, J.B. of New York University during the Summer of 1966 and again in the Winter and Spring of 1967. Their results were published in the Proceedings of the 1968 National Incinerator Conference (published by The American Society of Mechanical Engineers) and presented at the

MECAR Symposium on Incineration of Solid Wastes on March 21, 1967 in New York City.

The refuse in the pit was first mixed by the crane operator. Four individual grapple loads of 3/4 to 1 ton each were then subsequently studied on four different occasions. Each lot was hand sorted by 4 men into 11 categories. The refuse in each category was protected from moisture loss and weighed. The results obtained are tabulated in Table I.

Table 1

Composition of Refuse at the Oceanside Municipal Incinerator Plant

Percent by Weight

Category	Test 1 June 1, 1966	Test 2 June 23, 1966	Test 3 Feb. 21, 1967	Test 4 April 5,1967
Cardboard	1.59	6.75	5.78	6.81
Newspaper	8.88	11.27	21.35	12.75
Misc. paper(1)	22.25	21.78	26.20	24.70
Plastic film	1.76	1.77	1.20	1.09
Other plastics, etc.(2)	0.69	1.67	2.34	7.73
Garbage	9.58	10.21	16.70	7.23
Grass,dirt, leaves	33.33	19.00	0.26	17.89
Textiles	3.00	3.33	2.24	3.97
Wood	1.22	6.58	1.46	3.47
Mineral(glass,etc.)(3)	9.74	9.49	11.87	7.13
Metallic	7.96	8.15	10.60	7.23
	100.00	100.00	100.00	100.00

(1) Includes food cartons, paper towels, brown paper, mail and magazine paper, but excludes newspapers and corrugated boxboard.

(2) Includes rubber, molded plastics and leather goods.

(3) Includes glass, ceramics, bricks, mortar, cement and stones.

A variation of moisture content in the combined refuse of from 19 to 42% was experienced when no rain fell. Refuse non-combustibles and metals varied between 20 and 35% of the total refuse. Paper ranged between 33 and 53% of the refuse. The garbage (food waste) fraction ranged from 7.2 to 16.7%, 2/3 of which was moisture.

The pit contents were further, carefully, visually inspected, at each incinerator, on every occasion when stack samples were taken. Thus, the refuse was roughly and quite superficially compared with that at the Oceanside plant, which was scientifically sampled and analyzed (see table above). Any obvious, significant variation in the composition was recorded. Clearly this method of visual analysis must be taken only for what its worth for only the surface covering layer was in view. Nevertheless, by visual inspection, it may be said that the refuse collected at the East 73rd St., the Flushing and the Oceanside (during the fall and winter) plants appeared to be generally the same. The refuse at the Hamilton Ave. plant, collected primarily from an urban and industrial area, was discernably richer in textiles at the times samples were taken. Specifically, there appeared to be relatively greater quantities of colored carpet and other textile scrap. A very small, but often noticeable quantity of industrial refuse, admixed with the large bulk of domestic and household refuse, is routinely incinerated at this plant.

The refuse delivered to the Oceanside Municipal incinerator was collected mainly from a suburbian area. During the time samples

were collected for detailed analysis (spring and summer), the refuse in the pits contained a significant number of plastic bags filled with garden and yard trimmings and scraps, leaves, grass and dirt. Pieces of small wooden furniture (chairs, small tables) were predominant during the spring season. Refuse incinerated at the East 73rd St. plant was collected primarily in Manhattan. The composition did not seem to vary appreciably throughout the year. Refuse at the Flushing Municipal incinerator, collected from a primarily urban area, was in appearance the same as that at the East 73rd St. plant and did not seem to change significantly during the fall and winter seasons.

Sampling Apparatus

Representative sampling is of major importance in establishing the true composition of any complex system regardless of the accuracy of the analytical methods employed. The composition of the stack effluent from an incinerator buring municipal refuse is known to be quite complex. In order to conduct a meaningful exhaustive analysis of this effluent, a representative sample must be taken. This implies that all the components must be taken in the same proportion as they exist at the point of sampling. Obviously the latter must be carefully chosen. Those components of interest then must be efficiently and completely "trapped" either via filtration, absorption, chemical reaction, condensation etc. In addition, the quantity of sample taken for analysis must be large enough so that the components can be accurately quantitated employing predetermined analytical methods. High volume sampling,

concurrent with complete recovery of the desired fraction, is desirable from the stand point of time consumed.

The sampling apparatus and procedures used for the seasonal variation and incinerator comparison studies were in accordance with those described in "Selected Methods for the Measurement of Air Pollutants", U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Air Pollution, Robert A. Taft Sanitary Engineering Center, May 1965. A compact manifold, Figure 1, incorporating all of the necessary impingers, fritted bubblers, stopcocks, metering devices, pumps, vacuum gauges, etc. was constructed and successfully used for the quantative sampling of SO_2, NO_2, NO, total acids (organic as CH_3COOH and also HCl, HF, HCN and H_2SO_4) and total aldehydes. All the acids were collected in 1 N NaOH in Greenburg-Smith impingers. A 16 liter evacuated, stainless steel cylinder, fitted with a vacuum gauge, was used to collect samples (directly from the stack) for N_2, O_2, CO, CO_2 and total hydrocarbons analysis. Each sample was continuously collected over a period of about one hour. 1 to 2 liters respectively 1 to 2 lbs. quench water and ash samples were manually collected in appropriate glass jars.

Equipment used for the collection of representative samples for the exhaustive analysis of stack effluent (not including particulates) was designed, constructed and tested in the laboratory, and installed at the Oceanside Municipal Incinerator plant in Hempstead, Long Island, N.Y. Photographs of the assembly, Figures 2 and 3 were taken with the equipment in place at the sampling site (adjacent to stack No. 2). The

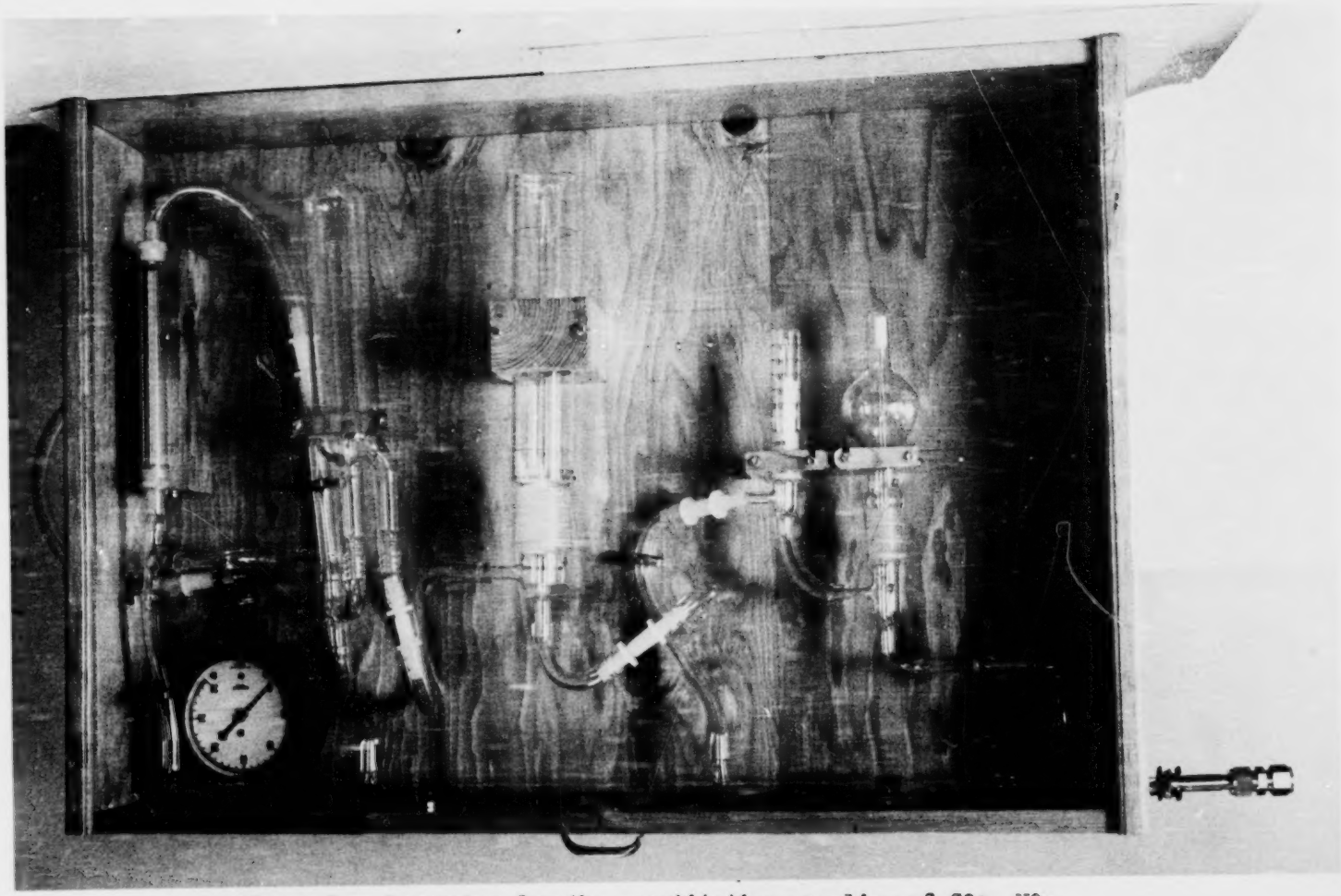

Figure 1. Apparatus for the quantitative sampling of SO_2, NO_2, NO, total acids (organic as CH_3COOH, HCl, HF, HCN and H_2SO_4) and total aldehydes.

apparatus, shown schematically in Figure 4, consists essentially of a probe which embodies a glass wool filter to trap particulates, two large volume and one small volume specially designed coil traps(*), a U-tube trap, a combination expansion chamber-heat exchange unit, flush-thru large volume gas sampling tanks, mercury manometer, thermometer, a dry gas meter and a high-volume vacuum pump. The probe, the traps and the sampling tanks were constructed of stainless steel; stainless steel tubing and valves were wide bore to permit high volume flow. The entire assembly readily permitted a gas flow of about 0.8 cubic feet per minute at a pressure of about 28 inches of mercury. During operation, the first two coil traps were maintained at $0^{\circ}C$ and the U-tube and small coil trap at $-78^{\circ}C$ (with dry-ice acetone). Representative samples of normally gaseous components not retained in the traps were collected in the flush-thru gas sampling tanks. The high collection efficiency of this trapping system was at first experimentally demonstrated in the laboratory using ambient air spiked with known quantities of volatile organics. It was subsequently proven in practice during preliminary test runs at Oceanside.

A first version of the sampling apparatus incorporated a separate filter located outside the stack several feet from the sampling port, a water-cooled coil condenser above the first coil trap, and a

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(*) The basic design of these traps appears in a paper by Yocom, J.E. Hein, G.M. and Nelson, H.W., J.A.P.C.A. 6,No. 2,84-89 (1956). The original traps were constructed and used to efficiently collect relatively large, representative samples of organics from a high-volume gas flow of backyard incinerator effluent.

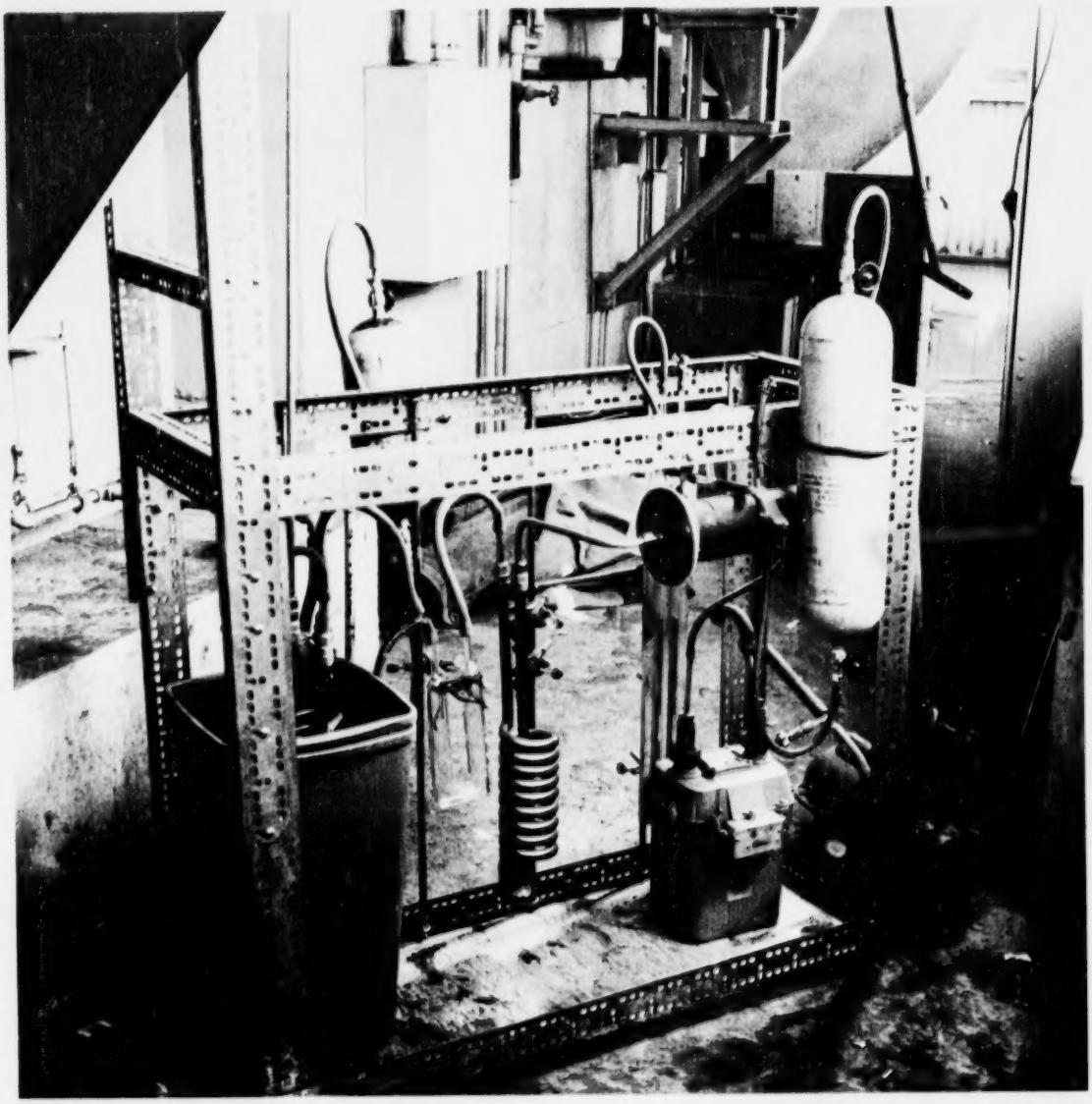

Figure 2. Apparatus for the collection of representative samples for the exhaustive analysis of gaseous stack effluent - on site.

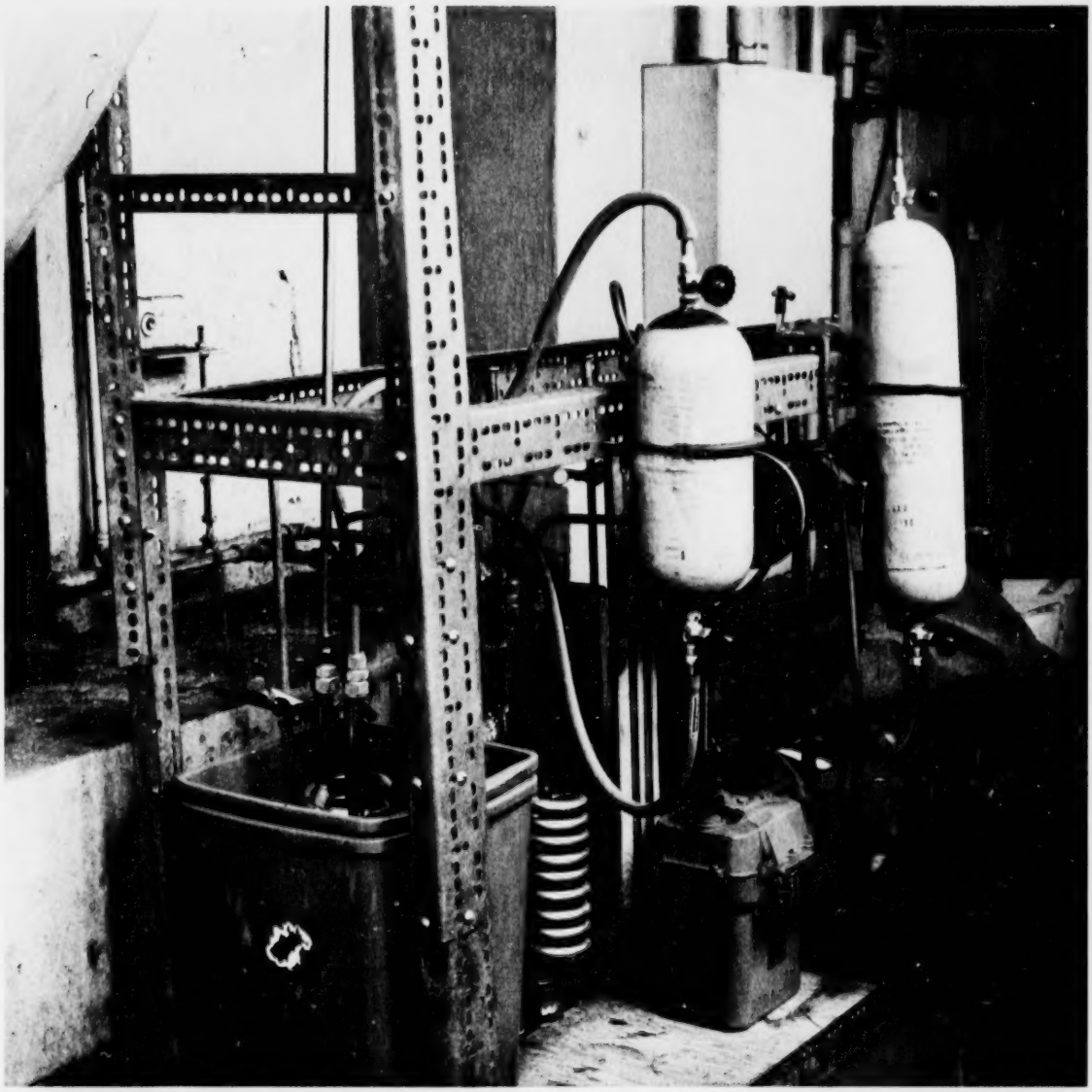

Figure 3. Apparatus for the collection of representative samples for the exhaustive analysis of gaseous stack effluent - on site.

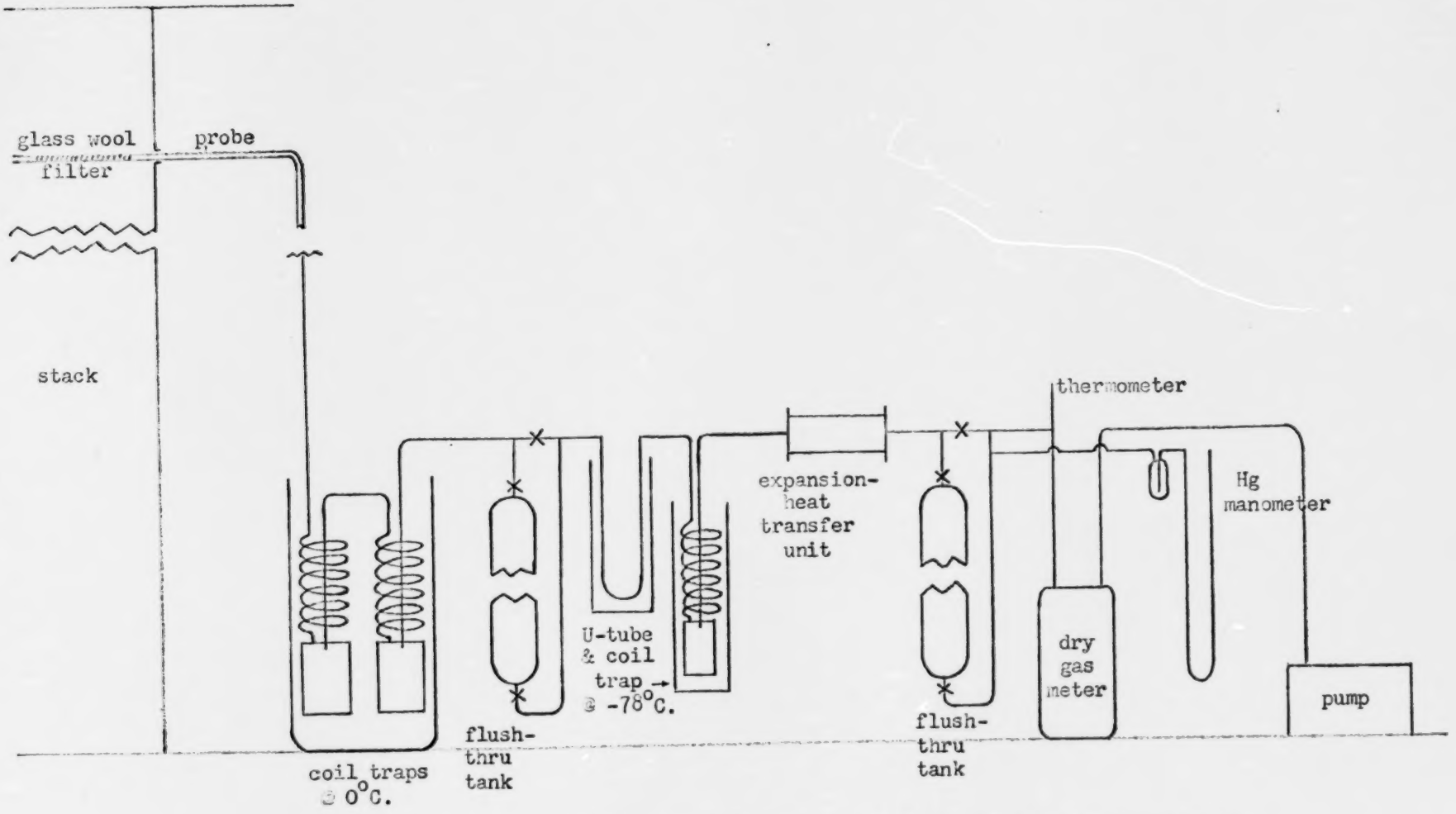

Figure 4. Schematic of apparatus used for the collection of representative samples for the exhaustive analysis of gaseous stack effluent.

spiral heat exchange unit after the third coil trap. During preliminary sampling tests at Oceanside, liquid collected in the separate glass wool filter which remained surprisingly cool throughout the test run. This unit was therefore eliminated and the glass wool placed in a section of the probe extending into the stack. The water-cooled coil condenser was eliminated after it was found that stack gas entering this unit was already at about ambient temperature. The spiral heat exchange unit was replaced by a large diameter, demountable stainless steel chamber in order to eliminate blockage by ice-crystals which were physically swept out of the -78°C cooled coil trap by the high volume flow of gas.

Velocity measurements were taken using an appropriate pitot tube following conventional velocity traverse techniques.

Analytical Procedures

SO_2, NO_2 and NO were quantitated in accordance with procedures described in "Selected Methods for the Measurement of Air Pollutants", loc. cit.. The hydrogen peroxide method was applicable to the determination of sulfur dioxide while the Saltzman method was found to be satisfactory for the determination of nitrogen dioxide and nitric oxide. Total aldehydes were quantitated following the method of Goldman, F.H. and Yagoda, H. of the Division of Industrial Hygiene, National Institute of Health, Bethesda, Md., Industrial and Eng. Chem., 15, No. 6, 377-378 (1943). Organic acids were quantitated as follows: Acetic, propionic and butyric via gas chromatography following neutralization, concentration and acidification of collection media (aq. NaOH), and formic via infrared spectrophotometry, following neutralization of reaction media

and isolation of salts resulting from complete evaporation ($NaNO_3$ was used as an internal standard). N_2, O_2, CO_2, CO, total hydrocarbons and hydrogen cyanide were quantitated gas chromatographically. Chloride was quantitatively determined using both the Volhard and the spectrophotometric method of Martens, H.H. of the Air Force Rocket Propulsion Laboratory, Edwards, Calif. (in-house report). Fluoride was quantitatively determined via the method of Willard, H.H. and Winter, O.B., Industrial and Eng. Chem., Anal. Edition, 5, No. 1, 7-10 (1933), which involves the volatilization of fluorine as hydrofluosilicic acid with subsequent titration of soluble fluoride and silicofluoride with standard thorium nitrate, using a zirconium-alizarin mixture as indicator. Sulphate was determined gravimetrically via precipitation of the barium salt.

Conventional wet chemical methods were employed in the analysis of the quench water. Residual organic matter in the ash samples was determined via ether extraction.

In the exhaustive analysis of gaseous stack effluent, identification and quantitation of specific organic components was primarily via gas chromatography and infrared spectrophotometry. Conventional wet-chemical, functional group tests were also employed.

Results of Seasonal Variations Study

As noted earlier, the East 73rd Street incinerator plant in Manhattan was chosen for this study. Samples were taken during each of the four seasons. The analytical results and rate of discharge data for each season are shown in Tables I thru IV; they are compared in Table V. The results of the quench water analyses and the organic contents of the ashes are compared in Table VI.

Table II

Some Stack Emissions from the East 73rd St. Incinerator
Manhattan, N.Y.C.
(Spring (May), 1968)

(N_2 = 77.7%, O_2 = 19.9%, CO_2 = 2.26%, CO = 0.01%)

Component	Conc. ppm/v	Rate of Discharge $ft.^3$/d.@356°F	Rate of Discharge $ft.^3$/d.@STP(1)	Rate of Discharge g. moles/d.	lbs./ d.	lbs./ton of Refuse
Effluent	-	851×10^6	511×10^6	643×10^6	41×10^6	98×10^3
SO_2	37	31,487	18,892	23,804	3352	8
NO_2	1.4	1,191	715	901	91	0.22
NO	2.4	2,042	1,225	1,544	102	0.24
Total HC as CH_4	410	348,910	209,346	263,776	9286	22.1
Total Acids(2) as HAc	2	1,702	1,021	1,286	170	0.41
Total Ald. as HCHO	1	851	511	644	43	0.10
HCl(3)	70	59,570	35,742	45,035	3617	8.6
HF(3)	3	2,553	1,532	1,930	85	9.20
HCN(3)	0	-	-	-	-	-
H_2SO_4(3,4)	53	45,103	27,062	34,098	352	17.5

(1) STP = 30" Hg and 32°F or 760 mm. Hg and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^-, CN^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table III

Some Stack Emissions from the East 73rd St. Incinerator, Manhattan, N.Y.C.
(Summer (August), 1968)

(N_2 = 79.3%, O_2 = 17.7%, CO_2 = 3.03%, CO < 0.01%)

Component	Conc. ppm/v	Rate of Discharge ft^3/d@536°F	Rate of Discharge $ft.^3$/d.@STP(1)	Rate of Discharge g. moles/d.	lbs./ d.	lbs./ton of Refuse
Effluent	-	772×10^6	381×10^6	480×10^6	30.6×10^6	51×10^3
SO_2	13	10,036	4953	6241	879	1.5
NO_2	0.6	463	229	289	29	0.05
NO	0.1	77.2	38.1	48	3.2	0.005
Total HC as CH_4	9.5	7334	3620	4561	161	0.27
Total Acids(2) as HAc	1.5	1158	572	721	95	0.16
Total Ald. as HCHO	0.4	309	152	192	13	0.02
HCl(3)	81	62,532	30,861	38,885	3,123	5.2
HF(3)	0	0	0	0	0	0
HCN(3)	-	-	-	-	-	-
H_2SO_4(3,4)	31	23,932	11,811	14,882	3,209	5.3

(1) STP = 30" Hg and 32°F or 760 mm Hg and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^-, CN^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table IV

Some Stack Emissions from the East 73rd St. Incinerator, Manhattan, N.Y.C. (Fall (October), 1968)

(N_2 = 78.7%, O_2 = 18.2%, CO_2 = 3.0%, CO = 0.05%)

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d$@(^oF)	Rate of Discharge $ft.^3/d$@STP(1)	Rate of Discharge g/moles/d.	lbs/d.	lbs/ton of Refuse
Effluent(5)	-	751×10^6 (532)	375×10^6	473×10^6	30×10^6	71×10^3
SO_2	31	23,281	11,641	14,668	2065	5
NO_2	0.42	315	158	199	20	0.05
NO	1.2	901	451	568	37.5	0.09
Total Ald. as HCHO	4.0	3004	1502	1893	125	0.30
Effluent(6)	-	824×10^6 (527)	412×10^6	519×10^6	33×10^6	52×10^3
Total HC as CH_4	16	13,184	6,592	8,306	292	0.46
Total Acids(2) as HAc	1	824	412	519	69	0.11
HCl(3)	41	33,784	16,892	21,284	1709	2.7
HF(3)	0	0	0	0	0	0
HCN(3)	-	-	-	-	-	-
H_2SO_4(3,4)	41	33,784	16,892	21,284	4589	7.3

(1) STP = 30" Hg and 32°F or 760 mm. Hg and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^-, CN^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

(5) Two furnaces in operation.

(6) Three furnaces in operation.

Table V

Some Stack Emissions from the East 73rd St. Incinerator, Manhattan, N.Y.C.
(Winter (February), 1969)

(N_2 = 78.2%, O_2 = 18.7%, CO_2 = 2.98%, CO = 0.05%)

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d$@527°F	Rate of Discharge $ft.^3/d$@STP(1)	Rate of Discharge g.moles/d.	lbs./d.	lbs./ton of Refuse
Effluent	-	700×10^6	350×10^6	441×10^6	28×10^6	67×10^3
SO_2	39	27,300	13,700	17,300	2430	5.8
NO_2	0.04	28	14	18	1.8	0.004
NO	0.34	238	119	150	9.9	0.024
Total HC as CH_4	60	42,000	21,000	26,400	940	2.14
Total Acids(2) as HAc	< 1	< 700	< 350	< 440	< 58	< 0.14
Total Ald. as HCHO	2.3	1,610	805	1,010	66	0.16
HCl(3)	76	53,200	26,600	33,500	2700	6.4
HF(3)	0	0	0	0	0	0
HCN(3)	0	0	0	0	0	0
H_2SO_4(3,4)	49	34,200	17,100	21,500	4600	11.0

(1) STP = 30" Hg and 32°F or 760 mm. Hg and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^-, CN^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table VI

Some Stack Emissions from the East 73rd St. Municipal Incinerator, Manhattan, N.Y.C.

Spring, Summer, Fall and Winter, 1968-69

Lbs./Ton of Refuse

Emission	Spring	Summer	Fall	Winter
SO_2	8	1.5	5	5.8
NO_2	0.22	0.05	0.05	0.004
NO	0.24	0.005	0.09	0.024
Total HC as CH_4	22.1	0.27	0.46	2.14
Total Acids as HAc	0.41	0.16	0.11	< 0.14
Total Ald. as HCHO	0.10	0.02	0.30	0.16
HCl	8.6	5.2	2.7	6.4
HF	0.20	0	0	0
H_2SO_4	17.5	5.3	7.3	11.0

Table VII

Analysis of Quench Water and Organic Content of Ashes

from the East 73rd St. Incinerator,

Manhattan, N.Y.C.

Spring, Summer, Fall and Winter 1968-69

	Spring	Summer	Fall	Winter
pH	5	5	10-11	9
Total Dissolved Solids mg./ml.	0.20	2.1	2.0	4.1
Anionic Content, mg./ml.				
Cl^-	0.04	0.22	0.38	0.55
$CO_3^= + PO_4^= + SiO_3^=$ as $CO_3^=$	0.45	0.10	0.10	0.14
$SO_4^=$	0.03	0.23	0.24	0.27
F^-	-	0.0	-	-
Ashes				
%/w Ether Soluble	3.0	2.7	1.9	0.4

Both the CO_2 and CO values listed in Tables II thru V are low. This is not indicative of poor combustion efficiency but rather the result of the dilution of combustion products plus excess combustion air by a continuous large volume feed of both cooling, non-combustion air (40,000 cfm) and cooling water (150 g.p.m.), of which about 2/3 vaporizes. This large volume of cooling air and water which admixes with the normal effluent also reflects a high effluent to refuse weight ratio.

The seasonal measurements in lbs./ton of refuse are compared in Table VI. Spring values were the highest, with the exception of total aldehydes. Hydrogen fluoride was found only in samples taken in the spring at the East 73rd Street Municipal incinerator. Summer measurements appeared in general to be the lowest with NO_2, organic acids and hydrogen chloride as exceptions. The least amount of hydrogen chloride was found in samples collected in the fall; the highest quantities were found in the winter and in the spring. This would seem to indicate that the refuse was generally richer in polymeric (plastic) materials during the winter and spring seasons. This appears to be the case (confer with Table I).

Sulfur dioxide and sulfuric acid values, as might be expected, seem to be related (note Tables II thru VI) i.e., they were both either high, intermediate or low. Total organic acid values remained essentially constant as did the total aldehydes.

Since the East 73rd Street municipal plant was operating at normal, steady state conditions during each period samples were taken, it must be concluded that variations in effluent composition were due primarily to the changing nature of the refuse charge.

The quench water was richer in dissolved solids during the winter while the ether-soluble organic content of the residual ash was the lowest at this time (Table VII). These two related facts indicate a high combustion efficiency at least at the time samples were taken. They are of course also indicative of the nature of the charge. The dissolved solids content of the quench water was lowest in the spring, while organics in the residual ash were the highest during this season. The fact that this indicates lower combustion efficiency is contradictory to the fact that the highest rates of discharge of inorganics were recorded in the spring. Incineration temperatures would also be expected to run somewhat higher during this season because of the increased plastics content of the refuse charge. On the other hand, the presence of increased quantities of bulky furniture and of grass and garden trimmings would be expected to have an opposite effect.

Summer and fall quench water and residual ash did not seem to differ significantly.

Results of the Incinerator Comparison Study

As noted earlier, the four municipal incinerator plants which were chosen for this study were the East 73rd Street in Manhattan, the Hamilton Avenue in Brooklyn, the Oceanside on Long Island and the Flushing in Queens. Stack effluent from each was sampled and analyzed both during the Fall, 1968 and Winter 1968-1969. The analytical results and rate of discharge data for each during both seasons are listed in Tables IV, V and VIII thru XIII; they are compared as lbs./ton of refuse, in Table XIV. The results of the quench water analyses and the organic contents of the ashes are compared in Table XV.

Table VIII

Some Stack Emissions from the Hamilton Ave. Municipal Incinerator
Brooklyn, N.Y.C.
(Fall (Oct.-Nov.), 1968)

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d@923^oF$	Rate of Discharge $ft.^3/d@STP$(1)	Rate of Discharge g.moles/d.	lbs/d.	lbs./ton of Refuse
Effluent	-	687×10^6	245×10^6	309×10^6	20×10^6	4×10^4
SO_2	24	16,488	5880	7416	1044	2.1
NO_2	0.6	412	147	185	19	0.04
NO	1.6	1099	392	494	33	0.07
Total HC as CH_4	4.2(5)	2885	1027	1294	45.6	0.09
Total Acids(2) as HAc	< 1	< 687	< 245	< 309	< 40.8	< 0.08
Total Ald. as HCHO	0.6	412	147	185	12	0.024
HCl(3)	45	30,915	11,025	13,900	1116	2.2
HF(3)	0	0	0	0	0	0
HCN(3)	-	-	-	-	-	-
H_2SO_4(3,4)	40	27,480	9800	12,360	2665	5.3

(1) STP = 30" Hg and 32^oF or 760 mm. Hg and 0^oC.

(2) Total acids include acetic, pripionic and butyric expressed as acetic acid.

(3) Cl^-, F^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

(5) A total hydrocarbon concentration of 20 ppm/v was recorded two weeks later under apparently the same (incinerator) operational conditions.

Table IX

Some Stack Emissions from the Hamilton Ave. Municipal Incinerator, Brooklyn, N.Y.C.
(Winter (January) 1969)

(N_2 = 79.4%, O_2 = 18.5%, CO_2 = 2.00%, CO = < 0.01%)

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d$@608°F	Rate of Discharge $ft.^3/d$@STP(1)	Rate of Discharge g.moles/d.	lbs./d.	lbs./ton of Refuse
Effluent	-	600×10^6	276×10^6	348×10^6	22×10^6	4.4×10^4
SO_2	15	9,000	4,150	5,200	730	1.5
NO_2	0.01	6	2.8	3.5	0.35	0.001
NO	0.05	30	14	18	1.2	0.002
Total HC as CH_4	8.0	4,800	2,210	2,800	100	0.2
Total Acids(2) as HAc	< 1	< 600	< 276	< 350	< 46	< 0.08
Total Ald. as HCHO	2.0	1,200	550	693	45	0.09
HCl(3)	89	53,400	24,600	31,000	2,480	5.0
HF(3)	0.9	540	250	315	14	0.03
HCN(3)	-	-	-	-	-	-
H_2SO_4(3,4)	50	30,000	13,800	17,400	3,730	7.5

(1) STP = 30" Hg and 32°F or 760 mm. Hg. and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as Acetic acid.

(3) Cl^-, F^-, CN^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table X

Some Stack Emissions from the Oceanside Municipal Incinerator
Hempstead, L.I.
(Fall (Nov.), 1968); No. 3 Furnace

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d@554^oF$	Rate of Discharge $ft.^3/d@STP$ (1)	Rate of Discharge g.moles/d.	lbs/d.	lbs./ton of Refuse
Effluent	-	183×10^6	89×10^6	112×10^6	7×10^6	47×10^3
SO_2	33	6039	2937	3696	520	3.5
NO_2	0.7	128	62	78	8	0.05
NO	2.0	366	178	224	15	0.1
Total HC as CH_4	240	43,920	21,360	26,880	946	6.3
Total Acids (2) as HAc	1	183	89	112	15	0.1
Total Ald. as HCHO	0.7	128	62	78	5	0.03
HCl (3)	113	20,679	10,057	12,656	1016	6.8
HF (3)	0	0	0	0	0	0
H_2SO_4 (3,4)	76	13,908	6,764	8,512	1835	12

(1) STP = 30" Hg and 32^oF or 760 mm. Hg and 0^oC.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table XI

Some Stack Emissions from the Oceanside Municipal Incinerator
Hempstead, L.I.
(Winter (Feb.), 1969); No. 3 Furnace

(N_2 = 78.9%, O_2 = 19.8%, CO_2 = 1.25%, CO < 0.01%)

Component	Conc. ppm/v	Rate of Discharge $ft.^3$/d@545°F	Rate of Discharge $ft.^3$/d@STP(1)	Rate of Discharge g.moles/d	lbs./d	lbs./ton of Refuse
Effluent	-	180×10^6	88×10^6	111×10^6	7×10^6	46.7×10^3
SO_2	27	4,900	2,400	3,000	430	2.9
NO_2	0	0	0	0	0	0
NO	0.06	11	5.3	6.7	0.44	0.003
Total HC as CH_4	150	27,000	13,200	16,600	590	3.94
Total Acids(2) as HAc	1	180	88	111	14.4	0.10
Total Ald. as HCHO	0.26	47	23	29	0.19	0.001
HCl(3)	96	17,300	8,500	11,700	940	6.3
HF(3)	0.65	12	5.7	7.2	0.32	0.002
H_2SO_4(3,4)	46	8,300	4,100	5,200	1,130	7.5

(1) STP = 30" Hg and 32°F or 760 mm Hg and 0°C.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

Table XII

Some Stack Emissions from the Flushing Municipal Incinerator
Queens, N.Y.C.
(Fall (November), 1968)

Component	Conc. ppm/v	Rate of Discharge $ft.^3/d@(^oF)$	Rate of Discharge $ft.^3/d@STP$(1)	Rate of Discharge g.moles/d.	lbs/d.	lbs./ton of Refuse
Effluent(5)	-	257×10^6 (698)	111×10^6	140×10^6	9×10^6	3×10^4
NO_2	0.3	77	33	42	4.3	.014
NO	1.9	488	211	266	17.6	.06
Total Acids(2) as HAc	1	257	111	140	18.5	.06
Total Ald. as HCHO	9.2	2364	1021	1288	85	.28
HCl(3)	38	9766	4218	5320	427	1.4
HF(3)	0	0	0	0	0	0
H_2SO_4(3,4)	39	10,023	4329	5460	1177	3.9
Effluent(6)	-	158×10^6 (581)	74×10^6	93×10^6	6×10^6	3×10^4
SO_2	20	3160	1480	860	262	1.3
Total HC as CH_4	160	25,280	11,840	14,880	524	2.6

(1) STP = 30" Hg and 32^oF or 760 mm. Hg and 0^oC.

(2) Total acids include acetic, propionic and butyric expressed as acetic acid.

(3) Cl^-, F^- and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

(5) Three furnaces in operation.

(6) Two furnaces in operation.

Table XIII

Some Stack Emissions from the Flushing Municipal Incinerator
Queens, N.Y.C.
(Winter (February) 1969)

(N_2 = 79.3%, O_2 = 19.4%, CO_2 = 1.32%, CO < 0.01%)

Component	Conc. ppm/v.	Rate of Discharge $ft.^3/d$@831°F	Rate of Discharge $ft.^3/d$@STP(1)	Rate of Discharge g.moles/d.	lbs/d.	lbs/ton of Refuse
Effluent	-	272×10^6	104×10^6	131×10^6	8.4×10^6	2.8×10^6
SO_2	29	7,900	3,010	3,800	530	1.8
NO_2	0.02	5.4	2.1	2.6	0.26	0.001
NO	0.05	13.6	5.2	6.5	0.43	0.001
Total HC as CH_4	21	5,700	2,180	2,750	96	0.32
Total Acids(2) as HAc	1	270	104	131	17	0.06
Total Ald. as HCHO	0.84	230	87	110	7.2	0.024
$HC\ell$(3)	40	10,900	4,160	5,250	420	1.4
HF(3)	0.85	230	88	111	4.8	0.16
HCN(3)	-	-	-	-	-	-
H_2SO_4(3,4)	25	6,800	2,600	3,280	700	2.34

(1) STP = 30" Hg and 32°F or 760 mm Hg and 0°C.

(2) Total acids include acetic, propianic and butyric expressed as acetic acid.

(3) $C\ell^-$, F^-, CN and $SO_4^=$ expressed as the respective acids.

(4) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^{=2}$ to some extent in alkaline solution.

Table XIV

Some Stack Emissions from Municipal Incinerators

New York City Metropolitan Area

Fall, 1968 and Winter 1968-69

Lbs./Ton of Refuse

	Fall				Winter			
Emission	73rd. St.	Hamilton Ave.	Ocean side	Flushing	73rd. St.	Hamilton Ave.	Ocean side	Flushing
SO_2	5	2.1	3.5	1.3	5.8	1.5	2.9	1.8
NO_2	0.05	0.04	0.05	0.014	0.004	0.001	0	0.001
NO	0.09	0.07	0.01	0.06	0.024	0.002	0.003	0.001
Total HC as CH_4	0.46	0.09	6.3	2.6	2.14	0.02	3.9	0.32
Acids as HAc	0.11	0.08	0.1	0.06	0.14	0.08	0.1	0.06
Total Ald. as HCHO	0.30	0.024	0.03	0.28	0.16	0.09	0.001	0.024
HCl	2.7	2.2	6.8	1.4	6.4	5.0	6.3	1.4
HF	0	0	0	0	0	0	0	0
H_2SO_4	7.3	5.3	12	3.9	11.0	7.5	7.5	2.3

Table XV

Analysis of Quench Water and Organic Content of Ashes

from Municipal Incinerators

New York City - Metropolitan Area
(Fall, 1968, Winter 1968-69)

	East 73rd. St.		Hamilton Ave.		Oceanside		Flushing	
pH	10-11,	9	9,	9	7,	6	7-7.2,	9
Total Dissolved Solids, mg./ml.	2.0,	4.1	0.90,	5.6	-,	-	1.0,	1.8
Anionic Content, mg./ml.								
Cl^-	0.38,	0.55	0.085,	0.85	-,	-	0.05,	0.34
$CO_3^= + PO_4^{\equiv} + SiO_3^=$ as $CO_3^=$	0.10,	0.14	0.14,	0.15	0.16,	0.32	0.24,	0.07
$SO_4^=$	0.24,	0.27	0.075,	0.40	0.04,	1.48	0.043,	0.12
Ashes								
%/w Ether Soluble	1.9,	0.4	3.97,	1.4	1.94,(2)	0.7	0.9,(1)	1.6(1)

(1) Organic (gross) residue recognizable e.g., hair, vegetable and fruit pieces, charred paper etc. This is not included in the ether soluble organic residue.

(2) Unwashed, fine, dry ashes from cool furnace grating. Charred pieces of paper visible.

In general, the lowest rate of discharge values were recorded at the Flushing Municipal Incinerator plant, a batch-type unit (Table XIV). The residual ash at this plant, however, was relatively rich in gross organic matter e.g., hair, vegetable and fruit pieces, charred paper etc. (Table XV). The low emission values are in this case indicative of relatively inefficient combustion. Thus, the relative incineration efficiencies of various different incinerator plants cannot be evaluated on the basis of the magnitude of the gaseous emission values alone. A consideration of the composition of the residue is necessary.

Of the three continuous units, the lowest rate of discharge values were recorded at the Hamilton Avenue Incinerator plant in the fall and in general also in the winter (Table XIV). This is somewhat surprising for two reasons. Firstly, because a noticeable quantity of industrial refuse, including some synthetic textile, is normally incinerated at this plant together with the domestic and household material. Secondly, because of the three continuous units the Hamilton Avenue plant is the only one without water sprays. Why inorganic gaseous emissions per unit weight of refuse should be higher at the two plants outfitted with water sprays cannot be fully explained. It should be mentioned however that the residual ash samples from the Hamilton Avenue plant contained the largest amount of ether-soluble organic material (Table XV).

Air borne emission from the East 73rd Street Incinerator stack was relatively richer in SO_2 and H_2SO_4. The Oceanside Incinerator

gaseous stack effluent had the highest hydrocarbon content. NO_2, NO, and organic acids values were essentially the same in all cases. HF was found in the effluent from three of the four units only in the winter samples (Table IX, XI, XIII and XIV).

Quench water from the Flushing plant had the lowest amount of dissolved solids. The grate ash from this plant was also richest in gross organic residue (Table XV). Anionic contents of quench water samples taken, during the fall and again in the winter, from each of the four incinerator plants are listed in Table XV. Carbonate values for all samples were essentially the same. Sulfate values were higher in the winter than in the fall.

Grate ashes from the Oceanside and the East 73rd Street incinerators contained essentially the same quantities of ether-soluble organics.

Detailed Analysis of Stack Effluent

As noted earlier, samples for the exhaustive analysis were taken at the Oceanside Municipal Incinerator plant in Hempstead, L.I. They were representatively collected at a point after the fly-ash arrestors, downstream of the induced draft fan, at all times when normally dry refuse was being incinerated in furnace No. 2. The analytical results and rate of discharge data are listed in Table XVI.

Table XVI

Some Gaseous Emissions from the Oceanside Municipal Incinerator, Hempstead, Long Island

(N_2 = 79.9%; O_2 = 13.55%, 13.4%, 12.8%, 11.6%; CO_2 = 6.15%, 6.23%, 5.73%, 7.4%;)
(CO = 0.037%, 0.027%, 0.046%, 0.090%; H_2O = 8.4 o/v (5.3 o/w), 8.2 o/v (5.3 o/w).)

Component	Conc. ppm/wt.	Conc. ppm/V	Rate of Discharge $ft^3/d@600^oF$	Rate of Discharge $ft^3/d@STP$(1)	Rate of Discharge g.Moles/d.	lbs/d.	lbs/ton of Refuse	Comments
Effluent(2)	-	-	115×10^6	53×10^6	67×10^6	4.2×10^6	14×10^3	No. 2 Furnace
Methane	3.0	5.6	644	297	375	13	.04	-
Ethane & Acetylene				TRACES				
High Boiling Hydrocarbon	0.04	0.007	0.81	0.37	0.47	0.17	0.0006	Class ident. by I.R., M.W. ~ 200
Benzene	0.005	0.002	0.23	0.11	0.13	0.021	0.00007	-
Formic Acid	114	70	8,050	3,700	4,700	480	1.6	-
Acetic Acid	1.2	0.6	69	32	40	5.0	0.017	-
Methanol	0.05	0.04	4.6	2.1	2.6	0.21	0.0007	-
Ethanol	0.01	0.06	6.9	3.2	4.0	0.42	0.0014	-
n-Butyl Alcohol	0.01	0.004	0.46	0.21	0.26	0.04	0.0001	-
n-Amyl Alcohol	0.01	0.004	0.46	0.21	0.26	0.04	0.0001	-

Table XVI (cont.)

Some Gaseous Emissions from the Oceanside Municipal Incinerator, Hempstead, Long Island

(N_2 = 79.9%; O_2 = 13.55%, 13.4%, 12.8%, 11.6%; CO_2 = 6.15%, 6.23%, 5.73%, 7.4%;)
(CO = 0.037%, 0.027%, 0.046%, 0.090%; H_2O = 8.4 o/v (5.3 o/w), 8.2 o/v (5.3 o/w).)

Component	Conc. ppm/wt.	Conc. ppm/V	Rate of Discharge ft^3/d@600°F	Rate of Discharge ft^3/d@STP(1)	Rate of Discharge q.Moles/d.	lbs/d.	lbs/ton of Refuse	Comments
High M.W. Alcohol	0.04	0.007	0.81	0.37	0.47	0.17	.0006	Class ident. by I.R., M.W. ~ 200
Keto Alcohol	0.04	0.007	0.81	0.37	0.47	0.17	.0006	Class ident. by I.R., M.W. ~ 200
Acetone	12.4	6.1	700	320	420	52	0.17	-
Methylethyl Ketone	0.05	0.02	2.3	1.2	1.5	0.21	0.0007	-
Acetaldehyde	0.07	0.04	4.6	2.1	2.6	0.30	0.001	-
Phenol	0.2	0.08	6.9	3.2	4.0	0.84	0.003	-
Alkyl Halides	NONE DETECTED		-	-	-	-	-	limit of sensitivity < 0.07 ppm
Hydrogen Cyanide	0.04	0.04	4.6	2.1	2.6	0.17	0.0006	Found in only one sample
Hydrofluoric Acid (3)	1.0	1.4	160	74	93	4.2	0.014	-
Hydrochloric Acid (3)	131	102	11,700	5,400	6,800	550	1.83	-
Selenium	0.05	0.02	2.3	1.2	1.5	0.21	0.0007	Se or as H_2Se by volume

Table XVI (cont.)

Some Gaseous Emissions from the Oceanside Municipal Incinerator, Hempstead, Long Island

(N_2 = 79.9%; O_2 = 13.55%, 13.4%, 12.8%, 11.6%; CO_2 = 6.15%, 6.23%, 5.73%, 7.4%)
(CO = 0.037%, 0.027%, 0.046%, 0.090%; H_2O = 8.4 o/v (5.3 o/w), 8.2 o/v (5.3 o/w).)

Component	Conc. ppm/wt.	Conc. ppm/V	Rate of Discharge $ft.^3/d@600^oF$	Rate of Discharge $ft.^3/d@STP$(1)	Rate of Discharge g.Moles/d.	lbs/d.	lbs/ton of Refuse	Comments
Effluent(4)	-	-	183×10^6 (554^oF)	89×10^6	112×10^6	7×10^6	47×10^3	No. 3 Furnace
Sulfuric Acid (3,5)	-	76	13,908	6764	8512	1835	12	-
Sulfur Dioxide	-	33	6,039	2937	3696	520	3.5	-
Nitrogen Dioxide	-	0.7	128	62	78	8	0.05	-
Nitric Oxide	-	2.0	366	178	224	15	0.1	-

(1) STP = 30" Hg and 32^oF or 760 mm. Hg and 0^oC.

(2) Stack effluent from No. 2 furnace.

(3) Cl^-, F^- and $SO_4^=$ expressed as the respective acids.

(4) Stack effluent from No. 3 furnace.

(5) Some contribution by SO_2 although $SO_3^=$ was not detected; $SO_3^=$ is air oxidized to $SO_4^=$ to some extent in alkaline solution.

The components of the gaseous effluent resulting from the incineration of municipal refuse are many and representative of numerous classes of both organic and inorganic substances. Thus one or more compounds representative of aliphatic, saturated and unsaturated, and aromatic hydrocarbons, organic acids, alcohols, keto alcohols, ketones, aldehydes, phenols, halogen and other inorganic acidsand inorganic acid anhydrides are listed in Table XVI. Also included are the very toxic hydrogen cyanide and selenium. Additional classes of compounds are known to be and presumed to be present.

Miscellaneous Studies

In evaluating periodical variations in the concentration of any one major component of incinerator stack effluent, it becomes quite important to be cognizant of variations over periods shorter than the ones in question. Thus, concentration variations due to seasonal changes will become meaningful only after having a knowledge of variations within a season while a record of monthly variations becomes meaningful only after having knowledge of variations which occur from week to week or day to day. Clearly, continuous monitoring of the species is the ultimate answer.

For example, on May 23, 1968, the concentration of total hydrocarbons as CH_4 in the effluent from the stack of the East 73 St. incinerator was recorded as 410 ppm/volume (see Table II). Because this value seemed exceptionally high, an additional six samples of the effluent were subsequently, similarly taken, on different days, and each

analyzed for total hydrocarbons as CH_4. The results were as follows:

on June 18	-	(about) 350 ppm/v
on June 19	-	4.6 "
on June 20	-	3.2 "
on June 26	-	8.5 "
on June 27	-	4.7 "
on June 28	-	4.2 "

Thus 2 "high", one in May and one in June, and 5 "normal" values were recorded over a relatively short period. Wet refuse may have been responsible for the first "peak" concentration recorded on May 23rd. The reason for the second "peak" concentration, recorded on June 18, is not known. It is nevertheless important to note that such situations can arise. Clearly, the magnitude of these variations must be taken into account in evaluating concentration changes at long time intervals.

It has been suggested that the combustion product of cigarette paper may prove hazardous to the smoker's health because of its selenium content. Since many tons of various kinds of paper and paper products are daily incinerated in a metropolitan area such as New York City, it became of particular interest to record selenium concentrations in municipal incinerator stack emission. The Oceanside Municipal Incinerator plant was chosen for this study.

Samples of incinerator stack effluent condensable at $0^{\circ}C$. (see sections on "Sampling Apparatus" and "Detailed Analysis of Stack Effluent"),

samples of stack effluent collected in a Greenburg-Smith impinger containing 1 N NaOH and fly ash were quantitated spectrophotometrically(*) for selenium.

The concentration of selenium in the three sample fractions collected are listed in Table XVII. Essentially all of this element and/or its compounds seem to be concentrated in fly ash collected from the (cyclone) fly ash arrestors.

(*) The sample is oxidized with conc. nitric acid. Se(IV) reacts with 2,3-diaminonaphthalene to form a red-colored and strongly fluorescent complex. The fluorescence intensity is measured at an exciting wave length of 390 mμ and a fluorescent wave length of 590 mμ. A linear calibration curve is obtained over the range 0 to 1 μg. of Se for 10 ml. of toluene (used to extract the complex). The absorbance of the solution sample is determined at 390 mμ. The calibration curves follow Beer's law over the range 0 to 20 μg. of Se per 5 ml. of toluene in a 1 cm. cell at this wavelength. This method was submitted to the Intersociety Committee on Manual of Methods for Ambient Air Sampling and Analysis for evaluation, editing and eventual publication.

Table XVII

Concentration of Selenium in Stack Effluent
Oceanside Municipal Incinerator
Hempstead, L.I.

Fraction	ppm/wt.
0°C Trap Condensate	0.05
Aq. NaOH Solubles (Impinger)	0 (*)
Fly Ash	0.7

(*) The sensitivity of the analytical procedure used to quantitate selenium is less than 0.01 μg.

The concentration of total hydrocarbons as methane in municipal incinerator stack effluent varied significantly over a relatively short period of days. Peak values of 350 and 410 ppm/v were recorded on two occasions. Clearly, such variations in the hydrocarbons emission concentration and possibly in the concentration of other species must be seriously considered in evaluating variations in concentration due to seasonal changes.

The concentration of selenium in three sample fractions are listed in Table XVII. Essentially all of this element and/or its compounds are concentrated in fly-ash collected from the (cyclone) fly-ash arrestors.

General Comments

The tabulated data clearly speaks for itself. Thus it becomes immediately apparent that municipal incinerator gaseous effluent is significantly richer in inorganics such as hydrogen chloride, sulfuric acid and sulfur dioxide than in organics such as hydrocarbons, aldehydes, alcohols, ketones, esters and organic acids. The presence of such relatively high concentrations of stable inorganic products and generally low concentrations of relatively unstable (at incinerator operating conditions) organic products indicates a high combustion efficiency. Hydrogen chloride is mainly a product of the incineration of chlorinated plastic material such as polyvinyl chloride while the incineration of sulfur-containing synthetic and natural rubber products undoubtedly contributes to the overall emission of sulfur oxides and sulfuric acid. Teflon like products and some insecticides would be a source of hydrogen fluoride.

Clearly, control of these emissions is indicated from the air pollution point of view and in order to eliminate, to a large extent, corrosion of metallic control and other equipment.

Also clear and quite important is the fact that the total hydrocarbon concentration in the effluent varies significantly over relatively short periods of time. Thus, if indeed, the concentrations of other gaseous species change equally frequently, then the tabulated results must be evaluated with this fact in mind. Continuous variations in the solids content of the quench water and in the organic content of

the residual ash might also be expected. With respect to the latter, the question of a truly representative sample also arises.

Recommendations for Future Work

A survey of the literature and a review of the data on air borne emissions from municipal incinerators clearly indicated a limited knowledge in this area and a real need for additional, basic information. This need was only in part satisfied as a result of the field and laboratory experimental work described and evaluated in this report.

Thus, although the above recorded, experimental data are extremely informative and significant, they also in turn clearly indicate a need for supplementary and new, additional study.

Municipal incinerator stack effluent is richer in inorganic than in organic components. Most of the inorganics are toxic and corrosive. Means to decrease such undesirable emissions either via modification of operational conditions and procedures, to include the addition of e.g. a carbonate to the refuse charge, or via the use of practical control equipment should be sought. Further study in this area is indicated.

The concentration of hydrocarbons and probably of other species in incinerator gaseous emission varies significantly over very short periods of time. A knowledge of such variations, during presumed normal, steady-state operation of the incinerator unit, is necessary in order to correctly extraprolate and evaluate measurements taken at infrequent intervals.

Incineration efficiency cannot be evaluated on the basis of the magnitude of gaseous emission values alone. A thorough consideration of the furnace residue appears also to be necessary in order to arrive at a meaningful conclusion. Study of this aspect should be expanded. Elemental material balances should prove quite valuable.

Water spray chambers designed to cool the very hot furnace combustion products prior to discharge do not seem very effective in removing water-soluble gaseous products. This question could be resolved by a quantitative analysis of the gaseous incineration products (on a dry basis) before entering the water spray chamber and after leaving it in conjunction with an analysis of the discharged spray water.

Gaseous emissions from rotary kiln incinerators have not been adequately evaluated. Such units are still being used to incinerate municipal refuse in some major cities in the U.S. e.g., the Coconut Grove incinerator in Miami, Fla. and the Southwest incinerator in Chicago, Illinois. Comprehensive discharge data from such units would be extremely informative and valuable.

The town of North Hempstead, L.I. incinerates municipal refuse in rocking grate furnace units with unusually long secondary combustion chambers. Stack emission from such units should presumably be lower in organic content. Substantiation of this might prove quite valuable especially in planning construction of future incinerator plants.

Emissions resulting from the incineration of other than municipal and household, domestic refuse have not been adequately labelled.

Most hospital complexes in the N.Y.C. and other large metropolitan areas are equipped with "pathological" incinerators. These units are used to incinerate refuse which the city is not permitted by law to collect e.g., animal waste and animals, infectious bandages, pads and other wrappings and disposable containers, bacterial cultures and bacteriological, pathological, biological and surgery wastes, etc. Such waste is usually rich in plastics.

These incinerators range in size. The Montefiore unit in the Bronx, N.Y.C. can handle 750 lbs. per day. Some are built to incinerate as much as 3000 lbs. per day.

There are 20 municipal and over 100 private hospitals in the city of New York. Each incinerate different quantities of these unique solid wastes. The total amount incinerated daily is significant. Emissions and rates of discharge from such incinerator units should be recorded.

Most municipal incinerators usually shut down late on Saturday and resume operations early on the following Monday. During the shut-down and the start-up operations, the furnace units do not operate under steady state conditions and incineration efficiencies may be expected to be quite low. Thus stack emissions during these periods are probably relatively rich in organics. The overall total hydrocarbons, organic acids, aldehydes, esters etc. emissions during the few hours may possibly be nearly as much as the total six day emission of these substances while the incinerator is operating normally. It thus beomes important to

establish the composition of the stack effluent and to determine the rate of discharge of various major components during the few hours preceding and up to shut-down and during the few hours following start-up until the incinerator operates normally.

The quantity of synthetic polymeric materials (plastics etc.) in municipal refuse is steadily increasing rapidly. It is currently approaching 5% of the total. 16 billion lbs. of plastics, 4 billion lbs. of synthetic fibers and many billions of lbs. of rubber products were produced in the United States in 1968. Almost all of these products will eventually be discarded as municipal, household refuse and much of it will be incinerated. Based upon present growth rates, almost 35 billion lbs. of polymeric wastes can be projected for 1975; possibly 15 billion lbs. of this will be derived from plastics; primarily as a result of household discards. In addition, packaging materials waste would add another 7 billion lbs./year, or more than today's input of plastics from all sources. Furthermore, these estimates do not reflect additional major application developments which will contribute to wastes derived from polymeric products. Certain of these major application developments are discussed in Modern Packaging, vol. 42, No. 5, 78 (1969). A major one relates to recent legislation permitting the use of polyvinyl chloride plastic bottles for beverages of all types, from milk to liquor. The replacement of natural by synthetic fibers such as the polyamides, polyesters and polyurethane is creating still another change.

Incineration of plastics presents a number of serious problems which eventually must be evaluated and resolved. Older incinerators were

not built for the high heat release of burning plastic. Excess air must be increased to counteract the heat. Also, incinerators burn less refuse per day as plastics require more oxygen for complete combustion. Thus as the percent of plastic in refuse increases, the total weight of refuse incinerated will decrease unless modifications are made to supply more combustion air. Small explosions due to plastics have been experienced. An additional difficulty in burning polymeric wastes is realized with incinerators built with a plastic clay mortar instead of the usual refractory materials. Polyvinylchloride (PVC) wastes adhere to the clay and during cleaning, chunks of mortar come out with burnt plastic.

The products of the efficient combustion of plastics are of course a major problem because of their expected significant contribution to air pollution. Combustion of PVC and PVC copolymers results in the formation of hydrogen chloride. Teflon-like materials will yield hydrogen fluoride while nitrogen-containing plastics such as polyurethane and melamine and urea resins burn at elevated temperatures to yield isocyanates, hydrogen cyanide and oxides of nitrogen.

But this is not the entire picture. Most polymeric formulations contain, in addition, plasticizers, stabilizers, flame retardants and pigments. All PVC type polymers for example, contain 1 to 3% lead and/or tin stabilizer compounds. For flame retardant application, phosphate plasticizers are employed for quality products. In such cases, 25 to 50 parts per hundred tricresyl phosphate (TCP) or other phosphates must be employed sometimes in conjunction with organic bromine or chlorine

compounds. Highly chlorinated waxes (70% Cl) in conjunction with antimony oxide, Sb_2O_3 offer a lower cost replacement for TCP etc. Sb_2O_3 is widely used (1:2 ratio by weight), together with such chlorinated paraffins as a polyolefin flame retardant. All flame retardant polyethylene wire and cable coverings contain roughly 30 weight percent Sb_2O_3 and chlorowax in appropriate proportions. Polyurethane foams for home use are required by law to contain a minimum of 20 parts of TCP or other phosphates to render such products fire proof. Organic bromophosphates are now being promoted and used because of greater efficiency. Propylene carpets and textiles contain such organic bromophosphates plus many other additives, primarily stabilizers including phosphates and triazoles (N-organic compounds).

Neoprene rubber of course contains substantial amounts of chlorine. Neoprene and other synthetic elastomers also contain varying amounts of various sulfur compounds. Depending upon the degree of vulcanizing, the desired sulfur contents range from 3-4% minimum to as much as 40% for hard rubber such as is used in automobile battery cases. Thiokol rubbers containing between 50 and 70% S, as well as lead peroxide (15%) as the curing agent are widely employed for hose, tubing sealing compounds and many other applications.

These additives, present in by no means minor proportions, are expected to contribute to the air pollution problem on incineration. HCl may be expected from chlorinated paraffins, HBr from organic bromo compounds, oxides of phosphorous or phosphoric acids from TCP, lead and

antimony compounds from certain stabilizers respectively pigments or flame retardants, SO_2 from sulfur-containing rubbers and oxides of N from nitrogen-containing polymers.

Thus the incineration of municipal refuse containing significant quantities of polymer material presents a serious multifaceted problem which will have to be coped with and resolved in the not too distant future. Clearly, steps should be taken now and not when the situation becomes serious.

A comprehensive study of the incineration of municipal refuse "spiked" with known quantities of polymeric waste of known composition should yield a great deal of highly significant and useful information.

APPENDIX

Air Borne Emissions from
Municipal Incinerators

Annotated Bibliography

BOOKS, REPORTS AND MISCELLANEOUS PUBLICATIONS

Black, R.J. and Davis, P.L.

Refuse Collection and Disposal, An Annotated Bibliography 1960-1961. Public Health Bibliography Series, No. 4, Supplement E, U.S. Department of Health, Education and Welfare, Public Health Service; Division of Environmental Engineering and Food Protection, Special Engineering Services Branch.

Five pertinent references which appear also in present annotated Bibliography of literature surveyed.

Engineering Foundation, Coordinating Committee on Air Pollution, Research into sampling, Analysis or Monitoring of Gaseous Pollutant Emissions from Stacks - Literature Search, 11, 1965.

Eight pertinent references which appear also in present annotated bibliography of literature surveyed.

Engineering Foundation, Coordinating Committee on Air Pollution, Research into Sampling, Analysis or Monitoring of Gaseous Pollutant Emissions from Stacks - Literature Search, Search No. 6269, August 21, 1963.

Two pertinent references which appear also in present annotated bibliography of literature surveyed.

Engineering Foundation, Coordinating Committee on Air Pollution,

Measurement of Stack Gas Velocity and Methods of Sampling Stack Gases and their Particulates - Literature Search, Search No. 6216, July 19, 1962

One pertinent reference which appears also in present annotated bibliography of literature surveyed.

Faith, W. L.

Air Pollution Control, 259 pages, published by John Wiley and Sons, Incorporated, New York 1959.

A chapter on "Gases" p. 142-178, includes a discussion of stack gas sampling and analysis. Contains a number of references.

International Research Group on Refuse Disposal (IRGRD),

Information Bulletin No. 19 (1963) and No. 20 (1964), Translated by Ferguson, Brooks and Kelly - Consulting Engineers, Incorporated. Reprinted with permission by the U.S. Department of Health, Education and Welfare, Public Health Service.

No information pertinent to present annotated bibliography.

Jacobs, M. B.

Chemical Analysis of Air Pollution, 430 pages, published by Interscience Publishers, Inc., New York 1960.

Includes a chapter on "Incinerator flue gas Analysis", p. 322-334 and one on "Stack sampling and Analysis", p. 140-169.

Magill, P. L., Holden, F. R. and Ackley, C.

Air Pollution Handbook, 670 pages, published by McGraw-Hill Book Company Inc., New York, New York 1956.

Emission from domestic and municipal incinerators tabulated on p. 1-47. Municipal incinerators discussed on pp. 13-15 to 13-17, requirements on p. 13-11.

Meetham, A. R.

Atmospheric Pollution, Its Origins and Prevention, third (revised) edition by Bottom, D.W. and Clayton, S., a Pergamon Press book published by the Macmillan Company, New York, 1964.

Incineration of refuse briefly discussed on pages 156 and 157. No quantitative emission data.

Stern, A. C. (Editor)

Air Pollution, 2 volumes, published by Academic Press, New York 1962. Includes a chapter on "Source testing and monitoring", by B.D. Bloomfield, V.1, p. 434-476, which discusses equipment and procedures for measurement of gas flow rate and for collection of samples from stack. Other related chapters.

White, A. H.

Technical Gas and Fuel Analysis, 319 pages, second edition, published by McGraw-Hill, New York, 1920.

Sampling (to include flues) and storage of gases, apparatus used, analytical methods and a chapter on chimney gases.

Winkler, C.

Handbook of Technical Gas-Analysis, 190 pages, second edition, published by Gurney and Jackson, London, England, 1902.

Gas sampling (from flues, furnaces or chimneys), measurements and analysis of gases are discussed.

PERIODICAL REFERENCES

1967

Walker, A. B.

Air Pollution Control Equipment for Incinerators.

A talk given at the Metropolitan Engineers Council on Air Resources Symposium "Incineration of Solid Wastes" on March 21, 1967, New York, N.Y. Access No. 7209.

A limited amount of work has been done on the measurement of gas emissions from both municipal incinerators and flue-fed (apartment house) incinerators. Data indicate that municipal incinerators (above about 100 tons/day) emit about 2#/ton of sulfur oxides, about 2 to 3#/ton of nitrogen oxides, and minor amounts (less than 1#/ton) of organic acids --- aldehydes, hydrocarbons, ammonia etc. Measurements made on a number of large continuous feed municipal incinerators indicate particulate emissions in the range of 6 to 36#/ton of refuse charged. The probable presence of chlorine and phosgene as the result of burning various plastics has as yet not been experimentally evaluated. The flue-fed incinerator might be a little more serious with regard to noxious gases e.g., in the range of 32#/ton of refuse with about 22# being organic acids, 5# aldehydes and the remaining 5#/ton consisting mainly of esters, ammonia, benzene, phenols, sulfur oxides and nitrogen oxides. Nothing has been reported on the control of gaseous emissions from municipal incinerators with the possible exception of an unexpected removal of sulfur trioxide (from 22 ppm down to 0.4 ppm) in a small bag filter

pilot unit. Control of particulate emissions from both municipal and flue-fed incinerators is generally discussed.

Gerstle, R. and Kemnitz, D. A.

Atmospheric Emission from Open Burning, Journal of the Air Pollution Control Association 17, No. 5, 324-327 (1967).

Emission data have been derived from the simulated open burning of municipal refuse, landscape refuse, and automobile components. he results confirm that disposal of refuse by open uncontrolled burning invariably leads to higher emissions than incinerators and creates an unnecessary air pollution problem. Tabulated emission data include values for CO_2, CO, hydrocarbons (as CH_4), CH_2O, organic acids (as acetic), NO_2 and twelve polynuclear hydrocarbons.

1966

Goder, R. and Marshalla, A.

Incinerator Testing Programs 1966, Proc. Natl. Incinerator Conference, 231-234 (1966). Paper presented at the National Incinerator Conference, American Society of Mechanical Engineers, New York City, May 1-4, 1966.

Report on the progress of incinerator testing programs since 1964, ASME Nat. Incinerator Conference. Actions and immediate objectives of the Air Pollution Control Association and the Incinerator Institute of America are presented in this paper. The Incinerator Institute of America's new test charges, procedures and instrumentation are discussed against a background of test

results accumulated and studied by the members. Field studies of large numbers of installations are hampered by complex testing procedures and the industry suffers from a lack of significant data for study.

Walker, A. B. and Schmitz, F. W.

Characteristics of Furnace Emissions from Large Mechanically-Stoked Municipal Incinerators, Proc. Natl. Incinerator Conference, 64-73 (1966). Paper presented at the National Incinerator Conference, American Society of Mechanical Engineers, New York City, May 1-4, 1966.

A summary of field test and laboratory analytical data on dust emission from several large, mechanically-stoked municipal incinerators of different grate configurations is presented. Data on dust loading and physical and electrical characteristics of the particulates are recorded and discussed. Summary of gas analyses at furnace outlet is tabulated. This contains values for CO_2, O_2, H_2O and excess air. Techniques of laboratory analysis are given.

Stabenow, G.

Survey of European Experience with High Pressure Boiler Operation Burning Wastes and Fuel, Proc. Natl. Incinerator Conference, 144-60, (1966). Paper presented at the National Incinerator Conference, American Society of Mechanical Engineers, New York City, May 1-4, 1966.

Large incinerators in European municipal service have stoker-fired water walled furnaces and boilers for power

generation. The principles, stoker design, burning rates, boiler design and high efficiency dust collection are discussed. Data on nine European and two Brazilian plants of European design are tabulated. Water walled furnaces allow the use of low excess air, which reduces the volume of flue gas to be cleaned.

Jens, W. and Rehm, F. R.

Municipal incineration and Air Pollution Control, Proceedings of National Incinerator Conference, New York, N.Y., May 1-4, 1966. Paper presented at the National Incinerator Conference, American Society of Mechanical Engineers, 74-83 (1966).

Comprehensive performance test data of a municipal incinerator incorporating three new control concepts i.e., of a new impingement-baffle fly ash collector system, an automatically controlled underfire-overfire air combustion control system, and a water recirculation, clarification and neutralization system, are described in detail. Test data are presented on a municipal incinerator plant's total performance utilizing these three systems. This includes the effect of varying capacity operation on the particulate emission performance, utilizing these control features. The sampled particulates from the stack emission tests, the clarifier or dust collector catch, and the furnace residue were analyzed spectrographically and wet chemically for various chemical components (cationic and anionic) and properties. Some sampled stack particulates were submitted to a sub-sieve particle size analysis and particle density determination.

Svrovatka, Z.

New Incineration System for Town Refuse, Czech, Heavy Ind. (Prague) 11, 15-18 (1966).

Boilers for the combustion of refuse have been constructed in Prague, Czech. Since varying types of refuse must be disposed of, and since the material must be predried, preheated, ignited at the proper time, and properly burnt out, problems exist. Perfect combustion is important in ensuring that the combustion products ultimately discharged are harmless. The incinerator system is described in detail. The combustion products pass three filters and an electrostatic precipitator before reaching the stack. The slag is sterile and the smoke from the chimney harmless. Clean air is maintained.

Kreichelt, T. E.

Air Pollution Aspects of Tepee Burners Used for Disposal of Municipal Refuse, PH S Publ. No. 999-AP 28, 35 pp. (1966).

This report covers an evaluation study of air pollution emissions based upon an extensive literature search and field trips to 15 tepee burners in 6 states. Smoke as a function of composition and rate of charge was observed, and the effects of burner charging methods, construction, and operational procedures on smoke emissions recorded. None of the Tepee incinerators observed in operation met normal visible emission limitations of air pollution control ordinances of most municipalities.

Rogus, A. C.

European Developments in Refuse Incineration, Public Works 97, (5) 113-17 (1966).

The major overall trends observed in Europe's incinerators include the following: a) Fewer but larger incinerators with progressively larger furnaces; b) provision for continuous, mild mixing and agitation of burning refuse; c) high roofed furnaced chambers; d) use of water-cooled walls and arches; e.) many waste heat boilers with steam and power generation; f) raw gas cleansing by electrostatic precipitation; g) ever increasing use of automation and mechanization and dependence on more sophisticated instrumentation.

Wolf, M. and Jacobi, J. W.

Refuse Burning - Mullverbrennung, Brennstoff - Waerme - Kraft (Dusseldorf) 18, No. 4, 169-70 (1966).

This is an annotated bibliography on refuse burning. Fifty-seven references cover technical problems and processes, description of plants already built, new plants either being built or planned, and the current state of the art in other countries of Europe and the U.S.A. Subjects treated include, chlorine corrosion in refuse fires, waste burning with and without heat utilization, and combinations of composting and burning.

1965

Flood, L. P.

Air Pollution from Incinerators - Causes and Cures, Civil Engineering ASCE, p. 44-52 (December 1965).

The author evaluates certain design principles which should be followed if an incinerator is to successfully burn the rate capacity of solid waste to a non-putrescible residue, without creating a nuisance. Temperature for complete burnout, turbulence for thorough mixing of the combustibles with the air and time to complete the combustion in the furnace are essential. Too much air only serves to cool the fire and check complete combustion, after causing smoke. The flue bed should be gently agitated for complete burnout. Effective dust cleaning equipment should be utilized to minimize dust emission. A high stack decreases ground level pollution. A continuous type incinerator will cause less pollution than a batch type. A water-cooled furnace permits higher burning temperatures. Three-shift operation avoids the pollution and deterioration of plants concomitant with repeated starts and stops. Incinerator practice abroad is generally and briefly discussed.

Rehm, F. R.

Test Methods for Determining Emission Characteristics of Incinerators, Informative Report Number 2, Journal of the Air Pollution Control Association 15, 127-131, 132-135 (1965).

This article reviews tentative codes for flue fed incinerators. Isokinetic sampling, particulate testing and a survey on incinerator particulate and odor testing by performance is included.

1964

Kaiser, E. R.

Refuse Composition and Flue-Gas Analyses from Municipal Incinerators, Proceedings of 1964 National Incinerator Conference, held at New York City, May 18-20, p. 35-51.

The analyses of the flue and stack gases from 18 municipal incinerators are tabulated and plotted. Analytical data include values for CO_2, O_2, CO, N_2 and excess air only. The C/(H) ratios were calculated in all cases. There is a marked difference between the analyses of the stack gases and those to be expected from the combustion of the composite refuse. Much of the difference can be accounted for by the carbon loss in the residue and oxidation of metallics. Results of analyses of the ash collected in incinerator plants and emitted from the stacks are also tabulated. Metals are reported as the metal oxide, sulfur as SO_3, organic matter as organics. The absorption of CO_2 by the fly ash probably has a negligible effect on the flue gas analysis and C/(H) ratio.

Hangebrauck, R., Van Lehmden, D. J. and Meeker, J. E.

Emissions of Polynuclear Hydrocarbons and other Pollutants from Heat-Generation and Incineration Processes, Journal of the Air Pollution Control Association, 14, No. 7, 267-278 (1964).

Air Borne Emission:
from Municipal Incinerators

July 1969

This paper presents emission data from a series of tests, for which the sources tested included typical combustion processes involving the burning of conventional fuels and of certain commercial and municipal solid wastes. In addition to obtaining over-all emission data from different sizes and types of combustion units, a primary objective of the study was to establish the relative importance of various combustion processes as contributors of benzo (a) pyrene and other polynuclear hydrocarbons with demonstrated or potential carcinogenic properties. The other pollutants measured included particulate matter, CO, total gaseous hydrocarbons (as CH_4), oxides of nitrogen, oxides of sulfur and formaldehyde. The polynuclear hydrocarbons emission rates from coal burning are higher than from oil or gas burning. BaP emission rates for the coal-burning units ranged from 19 to 400,000 micrograms per million Btu gross heat input and decreased as unit size increased. BaP emission rates for incinerators ranged from 0.075 to 260 micrograms per pound of refuse charged. The highest emission rates occurred in the small commercial sized units. Coal burning and refuse burning are most productive of solid particulates. Oxides of nitrogen are produced by the burning of all fuels and waste materials regardless of the quality of the combustion process. These compounds are formed in greater quantities in the larger heat-generating and incineration units. Oxides of sulfur emissions are of course a function of the sulfur content in the fuel burned. An excellent paper!

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1963

Bremser, L. W.

Incineration, Proceedings National Conference on Solid Waste Research (American Public Works Association - Special Report). Chicago, Illinois, December, 1963, p. 103-119.

General presentation on the problems of incineration. Air pollution considerations have been limited largely to concern over the discharge of particulate matter. Little is known about gaseous pollutants which may be discharged by incinerators. In summary, research is needed in all phases of incineration. We need to know the composition of the material to be burned and the gases to be treated and discharged. General discussion follows.

1962

Stenburg, R. L., Hangebrauck, R.P., Von Lehmden, D. J. and Rose Jr., A.H.

Field Evaluation of Combustion Air Effects on Atmospheric Emissions from Municipal Incinerators, Journal of the Air Pollution Control Association 12, No. 2, 83-89, (1962).

The field studies reported were conducted on two municipal incinerators having rated furnace capacity of 50 tons and 250 tons per 24 hour day. Both units were operated under essentially normal conditions during each test. Separate tests were made at several different levels of underfire combustion air over as wide a range as operating conditions would permit and solid particulate samples were collected under each test condition for comparison purposes. There does not appear to be

a critical level of underfire air for the larger units beyond which particulate emissions do increase significantly. Additional information was collected, and is tabulated, to provide other comparative data on the field operated municipal units and the small experimental incinerator. This includes measurement of gaseous pollutants i.e., oxides of nitrogen as (NO_2), total hydrocarbons (as hexane); the concentration was in all cases below the limit of detectability of the instruments used, formaldehyde and carbon monoxide. The determination of the effectiveness of a water spray scrubber on the 50-ton unit in reducing both gaseous and particulate emissions is also described.

1961

Stenburg, L., Hangebrauck, R. P., Van Lehmden, D.J. and Rose, Jr., A.H. Field Evaulation of Combustion Air Effects on Atmospheric Emissions from Municipal Incinerators, Paper presented at the Air Pollution Control Association, Annual Meeting, June 12, 1961, New York, N.Y. Paper also published in the Journal of the Air Pollution Control Association 12, 83-89 (1962). See reference with same authors and annotation under 1962.

Stenburg, R.L., Hangebrauck, R.P., Van Lehmden, D.J. and Rose, Jr., A.H. Effects of High Volatile Fuel on Incinerator Effluents, Journal of the Air Pollution Control Association 11, No. 8, 376-383 (1961). The effects of incinerator design and firing practices on the discharge of atmospheric pollutants from incinerators were

studied in order to establish design and operational standards for minimizing such discharge from industrial and municipal incinerators of the multiple chamber type. The extent to which operational factors affect emissions is emphasized by the wide range of results obtained. Minimization of pollutants cannot be affected by proper incinerator design alone but must depend on a combination of good design and proper operational procedures. Optimum combustion conditions would imply a temperature range of 1800° to 2000°F in the secondary chamber, the use of a relatively low proportion of underfire air, and the charging of fuel continuously or in small batches as opposed to large batch charges. The following were evaluated and the pertinent resulting data tabulated.

1) Effect of underfire airflow on particulate emissions;

2) Effect of excess air on oxides of nitrogen, formaldehyde and particulates;

3) Effect of fuel feed rate on particulate emissions;

4) Effect of secondary air on NO_2, hydrocarbons, CO, HCHO and particulates;

5) Effect of small vs. large batch charges on NO_2, hydrocarbons, CO, HCHO and particulates.

Fisher, H. A. and Langer, G.

New Instrumentation for Municipal Incinerators, 1961 American Public Works Association Yearbook, p. 224.

A description of an instrument that can produce immediate measurements of stack emissions. Developed by the Armour Research Foundation, this device will improve the design and

operation of municipal incinerators. Article describes the design of the primary component, a dynamic diluter, and a particle counter.

Popovich, M., Northcroft, N., Boubel, R. W. and Thornburgh, G. E.

Wood Waste Incineration, Robert A. Taft Sanitary Engineering Center Technical Report A 61-3, Cincinnati: U. S. Department of Health, Education and Welfare, Public Health Service, 1961, 5 pp.

A study of burning practices, emissions and reduction of smoke and cinders from tepee wood waste burners. A condensation of Wood Waste Disposal and Utilization, Bulletin No. 59, Oregon State Engineering Experiment Station, Corvialis, Oregon, 1958.

Sterling, M.

Air Pollution Control and the Gas Industry, Journal of the Air Pollution Control Association 11, No. 8, 354 (1961).

Thirty five different model incinerators were evaluated in conjunction with Detroit's new regulations on domestic incinerators. The tests showed that the new multiple-chamber incinerators with gas burners in the secondary chamber produced less smoke, odor and fly ash than the older types but required more heat input per pound of waste and took longer to incinerate a unit charge. The author lists eleven modifications of incinerator design that warrant further investigation.

Walsh, G.W.

Air Pollution Deterrents Refuse Removal Journal 4, No. 3, 21 (1961).

A discussion of three general techniques used to control air

contaminants, with emphasis on the control of pollutants from waste incineration and on particulate removal.

Stenburg, R. L., Van Lehmden, D. J., and Hangebrauck, R. P.

Sample Collection Techniques for Combustion Sources - Benzopyrene Determination, American Industrial Hygiene Association Journal 22 271-275 (1961).

Describes the development of techniques for collection of samples from high temperature combustion process gas streams. Sampling train is described.

1960

uttle, W. N. and Feldstein, M.

Gas Chromatographic Analysis of Incinerator Effluents, Journal of the Air Pollution Control Association 10, No. 6, 427-429 (1960).

Proposed regulations of the Bay Area Air Pollution Control District include emission standards for C_2 to C_6 hydrocarbons from incinerator effluents. It is stated that the total C_2 and C_6 hydrocarbon concentration should not exceed 50 ppm measured at standard conditions. The proposed regulation further states that the concentration of hydrocarbons should be measured by gas chromatography. A procedure for the gas chromatographic analysis of incinerator effluents is described and was used to analyse the effluents from incinerators. Results indicate that when the concentration of C_2 hydrocarbon is below 10 ppm, the C_3 to C_6 hydrocarbons are generally present in less than 1 to 2 ppm. When the C_2 species is present in high concentrations,

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the C_4 to C_6 compounds are generally present in significant concentrations. Some specific C_4 to C_6 compounds found in the effluents from incinerators have been identified.

Compton, C. R. and Bowerman, R. F.

Waste Disposal Without Air Pollution, Journal of the Air Pollution Control Association 10, No. 1, 57 (1960).

Air pollution problems caused by some of the common methods of waste disposal and salvage are discussed. Special attention is given to the ways of reducing stack emissions from municipal refuse incinerators, to sanitary landfillings, and to the disposal of troublesome liquid and solid industrial wastes.

Chase, R. L., Low, P. S., Lunche, R. G. and Shaffer, N. R.

Total Air Pollution Emissions in Los Angeles County; Journal of the Air Pollution Control Association 10, No. 5, 351-366 (1960).

Describes in detail the major sources of air pollution in Los Angeles County and the quantity of contaminants from each source. After the use of open fires and single-chamber incinerators were banned, emissions from the incineration of combustible refuse were reduced to a fraction of prior emissions. Results of studies show 1500 tons of hydrocarbons, 60 tons of aldehydes and ketones, 150 tons of other organic gases, 100 tons of aerosols, 700 tons of oxides of nitrogen, 550 tons of sulfur dioxide, and 5450 tons of carbon monoxide emitted daily. These emissions are catalogued by source and where possible, emission factors have also been included.

Kaiser, E. R., Halitsky, J., Jacobs, N. B. and Mc Cabe, L. C.

Modifications to Reduce Emissions from a Flue-Fed Incinerator, Journal of the Air Pollution Control Association 10, No. 3, 183 (1960).

An extensive study on reducing the emission of contaminants from flue-fed incinerators was made in New York City. The methods studied include charging of refuse only during non-burning periods, using gas burners to promote combustion, limiting the flow of combustion air, scrubbing the flue gas and combinations of these devices. Data on emissions to the atmosphere from flue gas are tabulated. Values for noxious gases namely, for aldehydes (as HCHO), ammonia, benzene, esters, nitrogen oxides (as NO_2), organic acids (as acetic), phenols (as phenol) and sulfur dioxide are included. Methane, ethylene, acetaldehyde, methyl alcohol, ethyl alcohol, propylene and acetone were identified mass-spectrographically, but not quantitated. Larger amounts of aromatics, lower hydrocarbons and other organic compounds were present but not identified. Smoke quantities, odor concentrations and total odor units are also reported.

Stenburg, R. L., Morsley, R. R., Merrick, R. A. and Rose, Jr., A. H.

Effects of Design and Fuel Moisture on Incinerator Effluents, Journal of Air Pollution Control Association 10, No. 2, 114 (1960).

A study conducted to determine the effects of fuel moisture content, the amount and distribution of combustion air, and the rate of burning on pollutant emissions, from incinerators.

Results are discussed with respect to solid contaminants, nitrogen oxides, hydrocarbons, carbon monoxide, smoke and odors. Most pronounced were the findings on the amount and distribution of combustion air. Underfire air appeared to be the variable having the greatest effect on particle emissions. Excess combustion air also produced a significant increase in pounds of total particulate per pound of fuel burned.

1959

Kaiser, E. R., Halitsky, J., Jacobs, M. B. and Mc Cabe, L. C.

Modifications to Reduce Emissions from a Flue-Fed Incinerator, New York University, College of Engineering, echnical Report 552.2, June 1959. Nat. Institutes of Health, U.S. Public Health Service Project S53.

Tests were conducted on the use of overfire air jets, supplemental gas firing, a stainless-steel secondary combustion chamber, a method of high-rate combustion, and a flue-gas scrubber. The devices are illustrated and the emissions are reported and compared with those from the unmodified incinerator. Estimated investment and operating costs for the incinerator modifications are included. Published also in the Journal of the Air Pollution Control Association 10, No. 3, 183 (1960).

See reference with same authors and annotation under 1960.

Rose, Jr., A. H., Stenburg, R.L., Corn, M., Morsley, R.R., Allen, D. R. and Kolp, P. W.

Air Pollution Effects of Incinerator Firing Practices and Combustion

Air Distribution, Journal of the Air Pollution Control Association 8, No. 4, 297-306 (1959).

This report covers the first phase of the multiple chamber incinerator study to obtain, on a test incinerator of fixed dimensions, information on the effect of varying: 1) Amount and distribution of combustion air, 2) burning rate as measured by the amount of fuel charged per hour, 3) amount of fuel per charge, and 4) the interval between stoking the burning fuel bed. A small, refractory-lined, multiple-chamber prototype incinerator was constructed for this study. A series of tests were made and all major findings are tabulated. Emission data include values for solid contaminants, hydrocarbons, CO, oxides of nitrogen and smoke and odor.

Kaiser, E. R., Halitsky, J., Jacobs, M. and Mc Cabe, L. C.

Performance of a Flue-Fed Incinerator, Journal of the Air Pollution Control Association 9, 85-91 (1959).

Describes test apparatus and procedures used on a New York City apartment house incinerator evaluation and flue gas analysis. Confer also with references, with same authors, and resp. annotations under 1960 and above under 1959.

1958

Lindorf, H.

Geschichte der Rauchprüfgeräte, Archiv fur technisches Messen, n. 274, 233-234 (1958); n. 282, 137-140 (1959).

History of flue gas analysers. Reviews chemical and physical methods of measurement. 126 references.

Sterling, M. and Bower, R.

Testing Gas Fired Domestic Incinerators, Proceedings of the Air Pollution Control Association, 51st Meeting at Pittsburgh, Pa., 1958, p. 29-1, to 29-19.

In Detroit, the domestic incinerator became a focal point of interest as an air pollution problem about 1952. The incentive to develop a publicly acceptable unit was fostered by the passage of a supplementary air pollution control law in 1956 limiting installation to those models which passed the Bureau's performance requirements. The investigators' main concern, based upon complaints and observations was the odor and smoke performance levels of the units. The pertinent facets of the Detroit regulations relate to the acceptable performance characteristics for smoke, odor and fly ash. Test apparatus is described. Different test charges including the AGA simulated garbage load were fired in the incinerators. Sufficient comparative data was obtained on 18 models from which facts or trends could be procured. A comparative listing of the data obtained is included in the Appendix. The recorded stack emission data include values for smoke emission, fly ash emission, odor emission, CO, CO_2 and O_2.

Jacobs, M. B., Braverman, M.M., Hochheiser, S. and Ettinger, I.

Sampling and Analysis of Incinerator Flue Gases, Proceedings of the Air Pollution Control Association, 51st Meeting at Pittsburgh, Pa., 1958, p. 7-1 to 7-11.

A comparatively simple apparatus for sampling of and procedure for the analysis of incinerator (apartment house) flue gases is described. The construction and emplacement of the sampling apparatus is detailed. Methods for sampling and analysis of inorganic gaseous components such as nitrogen oxide, sulfur oxides, hydrogen sulfide, ammonia, carbon monoxide, esters, aldehydes, benzene, phenols, and oxidizable sulfur compounds; and of smoke density are outlined. Results of the analyses are tabulated. The organic acids, aldehydes and esters are the more important (with the exception of CO) pollutants on a weight basis.

1957

Kanter, C. V., Lunche, R. G. and Fudurick, A. P.

Techniques of Testing for Air Contaminants from Combustion Sources, Journal of the Air Pollution Control Association 6, No. 4, 191-199 (1957).

The organization of the Source Testing Section of the Research Division of the Air Pollution Control District is described. Procedures used in initiating and conducting a test and in selecting sampling location are given. Methods used in testing combustion sources such as incinerators and boilers are discussed. Stack gas velocities measurements, and collection and analysis (spectrographic) of particulate and gaseous contaminants are also discussed. The results of spectrographic and chemical analyses may be expected to vary with the material

being burned. Data which have been collected in these types of tests are tabulated. Values for particulates composition (metals), SO_2, SO_3, nitrogen oxides (expressed as NO_2), organic acids (expressed as acetic acid), aldehydes (expressed as formaldehyde), hydrocarbons (expressed as hexane), acetylene and amonia are included. Calculations involved in the test procedures are given, with illustrations using typical test data. The APCD has a development program to improve methods and apparatus for field testing.

Rehm, F. R.

Incinerator Testing and Test Results, Journal of the Air Pollution Control Association 6, No. 4, 199-204 (1957).

Includes source material, stack sampling and test results on domestic, commercial and municipal incinerators. The county of Milwaukee limitation on dust emission is the recommended ASME limitation of 0.85 lb. dust/1000 lb. flue gas, adjusted to a 12% CO_2 basis or a 50% excess air basis. After considerable dust test experience on incinerators of all sizes, it was concluded that a properly designed, engineered and operated incinerator can be made to comply with this limitation. The results of final dustloading tests at the city of Milwaukee Green Bay Avenue incinerator are tabulated. Values for CO_2, O_2, CO and N_2 are included.

Daugherty, R. L.

Incinerator Testing and Test Results, Journal of the Air Pollution Control Association 7, 118-120 (1957).

Deals mainly with a written discussion of F. R. Rehm's paper "Incinerator Testing and Test Results", J.A.P.C.A. 6, 199-204 (1957), see above. Closure by F. R. Rehm.

Rehm, F. R.

Incinerator Testing and Test Results, paper presented at the 49th Annual Meeting of the Air Pollution Control Association held at Buffalo, N.Y., May 20-24, 1956, p. 6-1 to 6-17.

Confer with reference with same author and with annotation under 1957.

1956

Yocom, J. E., Hein, G. M. and Nelson, H. W.

A study of the Effluents from Back-Yard Incinerators, Journal of the Air Pollution Control Association 6, No. 2, 84-89 (1956).

An incinerator, typical of those used in the back yards of Los Angeles, was built and set up in the laboratory for this study. A mixture of paper, grass clippings, hedge trimmings, and similar materials commonly burned in the back yard incinerators in the Los Angeles area was used for the incinerator tests. Gaseous and normally liquid materials from the effluent were collected in a conventional laboratory freeze-out train, whose traps were connected in series and maintained at successively lower temperatures. The apparatus is diagrammed and described. Effluent identification and quantitation was via infrared spectrophotometry and wet-chemical analysis. Summary of test conditions and data for the sampling runs are

tabulated. Spectrograms of products are included. A summary of estimates for the expected ranges of concentrations of compounds in incinerator effluents is tabulated. Values (in mg./$m.^3$ of effluent and in lb./ton of charge burned) for methanol, acetone, a number of specific hydrocarbons, carbonyl sulfide, acids (as acetic), phenols (as phenol), aldehydes (as HCHO), ammonia (may include low molecular weight amines), oxides of nitrogen (as NO_2), acetaldehyde, esters, guaiacol and CO are included. Some complex mixtures could not be identified. This work emphasized the extreme complexity of incinerator gases. It also points out the need for more work toward identifying the chemical nature of this form of pollution as a means of assessing its importance in smog problems. Similar or even more detailed analyses should be conducted in effluents from municipal incinerators.

1955

Hutchison, D. H.

Preliminary Analysis of Domestic Incinerator Emissions, Air Pollution Foundation Report No. 3 (Session 11), p. 17-18 (1955). Report generated at Stanford Research Institute, Stanford, California.

Newspaper and garden trash were burned separately in a standard 6 cu. ft. domestic incinerator. Effluent gases were collected in a sampling bottle or separated by passing thru a freeze out train. Incinerator and collection equipment is diagramed. Aldehydes and acids are present to a greater extent

in paper fires. Effluents from grass fires contained appreciable quantities of ammonia and amines. Emission data include values for aldehydes as (HCHO), ammonia, nitrogen oxides (as NO_2), acids (as acetic acid) organics, solids and sulfur oxides (as SO_2). Data are compared with previously recorded values from municipal incinerator emissions.

Bush, A. F.

Physical Characterisitcs of Municipal Incinerator Emissions, Air Pollution Foundation Report No. 3 (Session II), p. 19-20 (1955). Report generated at Department of Engineering, University of California, Los Angeles, California.

The physical characteristics of municipal incinerator emissions, based on studies of the performance of three municipal incinerators in the L.A. area in 1950, are discussed. Particulate material amounts to about 3 to 5 lbs. per ton of refuse burned. This corresponds to 1×10^{15} to 20×10^{15} particles per ton of refuse burned, with more than half the particles being less than 0.1 micron in size. Principal gaseous constituents of the total mass of discharge are CO_2 and water vapor. A comparison of the particulate matter from a household incinerator to that of municipal incinerators indicates similar particle frequency.

Stanford Research Institute and Los Angeles County Air Pollution Control District

Incineration of Refuse, Air Pollution Foundation Report No. 2, VI.,

50-63 (1955). Also Stanford Research Institute, "The Smog Problem in Los Angeles County" (1954).

The amounts and types of refuse burned in Los Angeles County were estimated for the year 1950. These data, and also data extrapolated to 1953, are summarized. Incinerator design and operation are discussed. Emission data (1950) from a domestic incinerator are tabulated. Values for aldehydes (as CH_2O), ammonia, nitrogen oxides (as NO_2), acids (as acetic acid), organics, solids and sulfur oxides (as SO_2) are included. Emission data from the Alhambra Municipal Incinerator (1950) and data from wood-waste incinerator effluent (1948) are also tabulated. Values for CH_2O, ammonia, NO_2, acetic acid, organics, solids and SO_2 are included and expressed in mg./m^3, lbs./ton burned, tons/day and tons emitted daily to the atmosphere. The results of backyard incinerator tests are also given. Aldehydes emission was recorded.

1953

Chase, R. L. and Rose, Jr., A. H.

Discharge from Municipal Incinerators, Air Repair 3, No. 2, 119-123 (1953).

Institute of Engineering Research University of California, Series 37, Tech. Bull. No. 5, "Municipal Incineration", October, 1951).

Institute of Engineering Research, University of California, Series 37, Tech. Bull. No. 6, "Municipal Incineration", (November, 1951).

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